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THE NATIONAL SHIPBUILDING RESEARCH PROGRAM

Thermal Spray Manual

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Peterson Builders, Inc.

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FEBRUARY 1996
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THERMAL SPRAY MANUAL

A Project of

The National Shipbuilding Research Program

for

The Society of Naval Architects and Marine Engineers
Ship Production Committee
Welding Panel SP-7

Prepared By

PUGET SOUND NAVAL SHIPYARD
WELDING ENGINEERING
WELD SHOP
LABORATORY DIVISION
MACHINE SHOP

RAY TRAVIS
CHARLES GINTHER
STEVE VITTORI
MEL HERBSTRITT
JIM HERBSTRITT
NEIL ARMENTROUT
KEN AVERY
BILL WILLIAMS
BRIAN LAWLOR
TOM MARSH

APPROVED BY

S. C. NELSEN
Head, Welding Engineering Division

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JAMES BOYD

ROBERT BORTVEDT

JOHN MEACHAM

MICHAEL SULLIVAN

MICHAEL W. POE

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INTRODUCTION

This thermal spray manual is intended to be a working manual for its user. The user is expected to add and remove information as appropriate based on the users needs. This document provides fundamental information for a variety of intended users, such as:

* DESIGN ENGINEERS
* THERMAL SPRAY ENGINEERS
* PRODUCTION SHOP SUPERVISORS
* JOURNEYMAN THERMAL SPRAY OPERATORS
* SHOP PLANNERS
* MACHINIST

The purpose of this manual is to provide fundamentals and to assist in the use of the thermal spiny processes in the refurbishment of shipboard machinery components by aiding individuals in:

* THE SELECTION OF APPROPRIATE APPLICATIONS
* TRAINING METHODS
* APPROPRIATE COATING SELECTIONS
* METHODS OF PROCEDURE QUALIFICATION
* SELECTION OF THERMAL SPRAY PROCESSES
* MASKING TECHNIQUES
* SURFACE PREPARATION TECHNIQUES
* SPRAYING TECHNIQUES
* ASSOCIATED MACHINING TECHNIQUES

To aid individuals in making sound thermal spray decisions, applicable basic information is contained within various section of this manual.

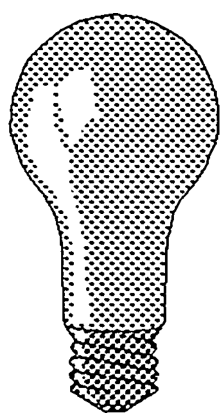
It is the intent of this manual to provide some fundamental structure to be able to find basic information easily and to build upon it. Fundamental information about thermal spraying, coatings, procedure and operator qualification, coating selection, and applications is contained in this manual.

From a thermal spray engineering stand point, this manual is intended to aid designers in making the best decisions as to repair applications, and coating system selections.

INTRODUCTION

This manual is designed to be a guide in preforming daily tasks, as a training aid, and as a foundation for building a sound thermal spray program and developing a dedicated staff ith knowledgeable personnel.

GLOSSARY



PREPARED BY: PUGET SOUND NAVAL SHIPYARD

ABRASIVE Material used for cleaning and/or for final surface preparation for applying a thermal sprayed coating. For the final surface preparation of machinery components, aluminum oxide is normally used.

ACETYLENE A fuel gas that can be used in the flame wire and flame powder thermal spray processes.

ADHESION A binding force that holds together molecules of substances whose surfaces are in contact or near proximity.

ALUMINA: A chemical compound (aluminum oxide); a ceramic used in powder or rod form in thermal spraying operations. May also be a blasting medium.

ANCHOR-TOOTH PROFILE The condition of the substrate after abrasive blasting for surface roughening.

ARC WIRE PROCESS: A thermal spray process where a heating zone is created by an arc between two continuously fed metallic wires, one positively charged and one negatively charged. The heating zone melts the wire material and compressed air or an inert gas is used to propelled the molten material to the substrate.

ARC: A luminous discharge of electrical current crossing the gap between two electrodes.

ARGON: An inert gas that can be used in plasma powder thermal spray process.

BASE MATERIAL The material of the component being thermal sprayed.

BLASTING: A method of cleaning or surface roughening by a forcibly projected stream of sharp angular abrasive.

BOND COAT A preliminary (or prime coat) of material that improves adherence of the subsequent spray deposit.

BOND STRENGTH: The force required to pull a coating free of a substrate, usually expressed in psi (kPa).

CARRIER GAS: The gas used to carry powdered material from the powder feeder or hopper to the thermal spray gun.

CERAMICS: Various hard, brittle, heat and corrosion-resistance materials normally used as the final coat with the thermal spray process.

CERMET: A physical mixture of ceramics and metals; examples are alumina plus nickel and zirconia plus nickel.

COATING SYSTEM: One or more thermal spray coatings that are qualified for use singly or in combination. An example of a one coating system is a stainless steel coating applied for restoration of dimensions. An example of a two coating system is a nickel base bond coat and ceramic final coat.

COATING STRESS: The stresses in a coating resulting from rapid cooling of molten material or semimolten particles as they impact the substrate. Coating stresses area combination of body and textural stresses.

COATING: (1) The act of building a deposit on a substrate, (2) the spray deposit.

COEFFICIENT OF THERMAL EXPANSION: The ratio of the change in length per degree rise in temperature to the length at a standard temperature such as 68°F (20°C).

COMPOSITE: Each grain contains all chemical elements present in the powder, but they are not alloyed.

DEFECT: A discontinuity or group of discontinuities that by nature or accumulated effect (for example, total crack length) render a part or product unable to meet minimum applicable acceptance standards or specification. This term designates rejectability.

FINAL COAT: The last coating to be applied during the thermal spraying sequence.

FIXTURING: Mechanical positioning to support the machinery component and thermal spray gun.

FLAME WIRE PROCESS: A thermal spray process that uses an oxygen fuel flame to create a heating zone. A wire is then continuously fed into the heating zone where is melted and atomized and then propelled to the substrate by the force of the burning gasses and compressed air.

FLAME POWDER PROCESS: A thermal spray process that uses an oxygen fuel flame to create a heating zone. Powder is fed into the heating zone and melted. The molten material is then propelled to the substrate by the force of the burning gasses and compressed air.

FRETTING: Surface damage resulting from relative motion between surfaces in contact under pressure.

GRIT BLASTING: See Blasting.

HELIUM: An inert gas that can be used in the plasma powder thermal spray process.

HIGH VELOCITY OXYGEN FUEL PROCESS: A thermal spray process where oxygen and fuel are mixed at high pressures. This mixture is ejected from a nozzle and ignited.
Into the high velocity flame powder is injected. The powder is propelled to the substrate by the force of the burning gases. When the thermal spray material collide with the substrate it plasticizes and forms a coating.

HYDROGEN: A fuel gas that can be used with plasma powder and high velocity oxygen fuel thermal spray processes.

INERT GAS: A gas which does not normally combine chemically with the substrate or the deposit.

INTERFACE The contact surface between the spray deposit and the substrate and between the bond coat and final coat.

INTERPASS TEMPERATURE In multiple pass thermal spraying, the temperature (minimum or maximum as specified) of the deposited thermal spray coating before a subsequent pass is started.

MASKING: The method of protecting the areas adjacent to the area to be abrasive blasted and thermal sprayed.

MECHANICAL BOND: The principal bond that holds thermal spray materials together and is formed between base metals and filler metals in all processes.

METALLIZING: See preferred term “thermal spraying”.

MICROMETER Any device for measuring minute distances, especially one based on the rotation of a freely threaded screw.

MUST The word “must” is to be understood as mandatory for the purpose of avoiding coating failures. *

NITROGEN: An almost inert gas that can be used with the plasma powder process.

NONTRANSFERRED ARC: An arc established between the electrode and the constricting nozzle. The workpiece is not in the electrical circuit.

NOZZLE (1) A device which directs shielding media, (2) a device that atomizes air in an arc wire spray gun, (3) the anode in a plasma gun, (4) the gas burning jet in a powder, rod, or wire flame spray gun.

OXIDES: A binary compound of an element or radical with oxygen.

OXYGEN A gas that is used with the flame wire, flame powder, and high velocity oxygen fuel thermal spray processes.

PARAMETER A measurable factor relating to several variables; loosely used to mean spraying variable, spraying condition, spraying distance, angle gas pressure, gas flow, etc.

PASS: A single progression of the thermal spray device across the surface of the substrate.

PLASMA POWDER PROCESS: A thermal spray process where a heating zone is created by an arc between a tungsten electrode and a nozzle. A gas or gas mixture is passed through this arc. This gas or gas mixture then exits the nozzle, forcing the flame outside the gun. A powder is fed into the flame where it is melted and propelled to the substrate by the force of the gas or gas mixture.

POROSITY: Cavity type discontinuities within a thermal sprayed coating.

PREHEAT: Heat applied to the substrate prior to thermal spraying. This may be performed to remove moisture and/or to reduce residual stresses.

PRIMARY GAS: The major constituent of the arc gas fed to the gun to produce the plasma; usually argon or nitrogen.

PROCEDURE The detailed elements of a process or method used to produce a specific result.

PYROMETER. An electrical thermometer for measuring high temperatures.

QUALITY ASSURANCE (QA): The activity of providing to all concerned the evidence needed to establish confidence that the quality function is being performed adequately (from the Juran Quality Control Handbook, 3rd edition).

SEALER: Material applied to thermal sprayed coatings to close pores and facilitate finishing.

SECONDARY GAS: The minor or second constituent of the arc gas fed to the gun to produce plasma.

SHADOW MASKING: A protective device that partially shields from a small distance above the work, thus permitting some overspray to produce a feathering at the coating edge.

SHOULD: The word “should” is to be understood as advisory for the purposes of improving coating quality and/or increasing the efficiency of the operation.

SHOULDER Area of component at the end of the undercut.

SOLVENT CLEANING: A method used to remove contaminants from the machinery component that is to be thermal sprayed.

SPALLING: The flaking or separation of a thermally sprayed coating.

SPLAT: A single thin flattened sprayed particle,

SPRAY ANGLE The angle of particle impingement, measured from the surface of the substrate to the axis of the spraying nozzle.

SPRAY DISTANCE The distance maintained between the thermal spraying gun nozzle tip and the surface of the component during spraying.

<u>SPRAY RATE</u> The rate at which surfacing material passes through the thermal spray gun.

<u>SUBSTRATE</u> Any material to which a thermally sprayed coating is applied.

<u>SURFACE PREPARATION</u> The operation necessary to produce a desired or specified surface condition.

<u>SURFACE FEET PER MINUTE</u>: The circumferential velocity of the substrate.

<u>TENSILE BOND STRENGTH</u>: See preferred term, "bond strength. ”

<u>THERMAL SPRAYING:</u> A group of processes where freely divided metallic or non-metallic materials are deposited in a molten or semi-molten condition to form a coating.

<u>THERMAL SPRAY GUN</u> A device for heating, feeding and directing the flow of a surfacing material.

<u>TRAVERSE SPEED</u>: The linear velocity at which the thermal spray gun traverses across the substrate during the spraying operation.

<u>TSJCR</u> Thermal Spray Job Control Record.

<u>TURNING FIXTURE</u> Mechanized equipment (i.e. lathe and traversing gun mount) that keeps the gun to-substrate distance and spray angle freed during spraying and the relative movement between the gun and substrate accurately controlled.

<u>UNDERCUTTING:</u> A step in the sequence of surface preparation involving the removal of substrate material.

<u>WORKPIECE</u> The object or surface to be coated. See preferred term substrate.

* Although guidelines using the word "must" can generally be shown to have exceptions, the experience of the authors has been that any exceptions are so minor in nature or frequency that they should be disregarded. (See definition of "should").

* Definitions of Thermal Spray terms can be found in the American Welding Society’s Thermal Spraying Manual “Practice, Theory, and Application”.

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AND
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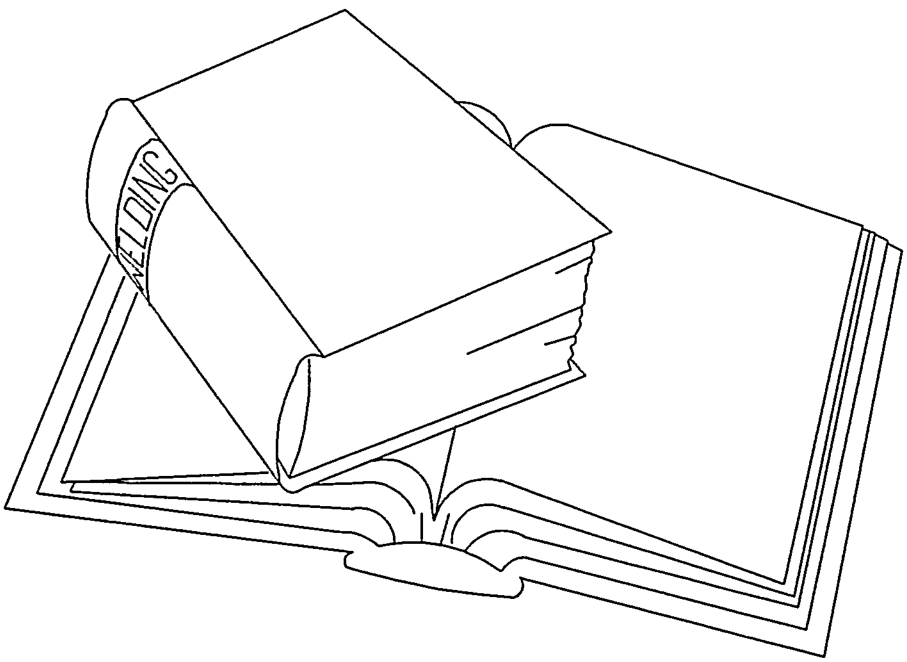

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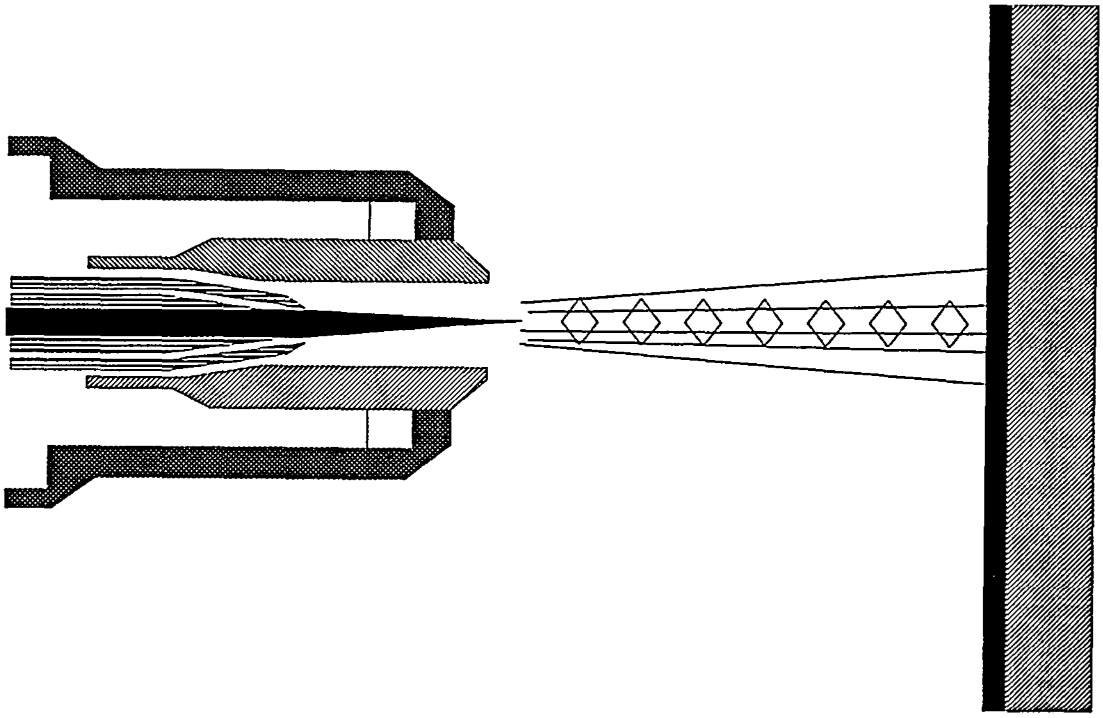
SECTION 1

FUNDAMENTALS
OF
THERMAL SPRAYING



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1 FUNDAMENTALS OF THERMAL SPRAYING

THERMAL SPRAY PROCESS

Thermal spraying is a group of processes in which freely divided metallic or nonmetallic surfacing materials are deposited in a molten or semimolten condition onto a prepared substrate to form a deposited coating. The thermal spray process normally is a cost-effective method for achieving equipment repair or improving new or used equipment performance. The process is an excellent repair method and should be considered, when appropriate, in lieu of other processes. Some of the potential problems of competing processes include the following:

1. Welding existing components may cause unacceptable distortion, cracking, or heat treatment problems. Precise identification of the base metal is required for welding. Some alloys are difficult or impossible to weld. Welding frequently lowers the fatigue life of the component.

2. Electroplating may be too slow or too limited in buildup capability, and it is environmentally hazardous.

BENEFITS

Advantages of using the thermal spray process for machinery components include the following:

1. BETTER THAN NEW - Thermal sprayed coating properties can be tailored to suit the application. Coatings (metallic and ceramic) can restore or attain desired dimensions, provide electrical or thermal shielding or conduction, or improve the resistance to abrasion, corrosion, or high temperatures. Thermal sprayed coatings can provide superior service to the extent that some coatings can extend the service life of mating components. For some of these applications, facilities are thermal spraying new components before being placed into service, to further extend equipment service life. In short, thermal sprayed coatings are capable of making many components significantly better than new.

2. NO DISTORTION OR HEAT AFFECTED ZONE-Although the substrate is normally preheated, the thermal spray process is still considered a metallurgically cold process. This means that, in most applications, no distortion or heat affected zone is created. This is due to the fact that components generally are kept cooler than 400°F during the entire spraying process.

3. VARIED SERVICE APPLICATIONS - Current thermal spiny applications in the shipbuilding and ship repair industry include thermal spraying of metallic materials on pump shaft bearing journals, turbine rotor shaft labyrinth seal areas, impeller fit areas, oil fit areas and various other types of applications. Ceramic coatings have been applied to the packing areas of valve stems and other types of packing and seal areas, giving those areas a smoother longer lasting surface than the substrate material thus enhancing the service life of that component. Thermal sprayed coatings can also serve for clearance control by applying abradable coatings at contact points.

4. **PART AVAILABILITY** - Parts availability plays a significant role in determining whether or not to use thermal spray repair methods. For some older machinery components, parts may simply be unavailable for a variety or reasons. For other items, ordering lead times may be unacceptable due to ship availability requirements. For still other high-cost items, new prices may be several times the cost of thermal spray repairs. In all of these cases, cost savings quickly add up, especially when factoring in the cost of ships unavailable for service commitments.

THERMAL SPRAY SYSTEMS

Shipbuilding and ship repair facilities use five primary thermal spray processes. These processes are the plasma powder process, the arc wire process, the flame powder process, the flame wire process, and the high velocity oxygen fuel process.

All thermal spray processes utilize five basic components. These components vary widely from one manufacturer or process to another, yet these components perform the same basic function (See Figure 1.1).

1. The Thermal Spray Gun is the heart of the system. This is where the heating zone forms and where the spray media enters the spray stream.

2. The Control System provides monitoring and control capabilities for the spray system. Operators use it to set and monitor gas flows and energy levels.

3. The Thermal Energy Supply may be electricity, or combustion from fuel gasses.

   Compressed gasses include compressed air for cooling and/or atomizing, fuel gasses, and inert gasses used for various functions, such as for plasma and powder carrier gas for powder feeders.

5. The final basic component is the Spray Media Feed System. This system delivers the spray media, usually in either wire or powder form, into the heating zone at a freely controlled rate. The controls for the feed system may be stand-alone or integrated with the spray gun control system.

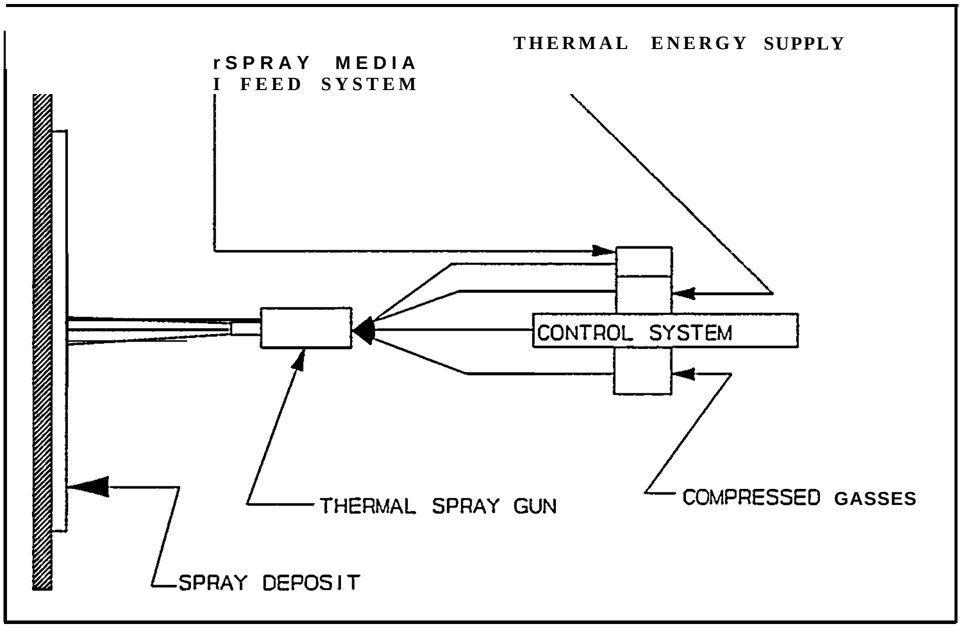

Figure 1.1 THERMAL SPRAY SYSTEM

PLASMA POWDER PROCESS

With the plasma powder process, an arc that is created between a tungsten electrode and a copper nozzle produces the heating zone. The tungsten electrode and nozzle are located in a conducting channel inside the plasma powder gun. A gas or gas mixture passes through this channel. The arc in the gas channel excites the gas into a plasma state, creating temperatures higher than can be obtained with any type of oxygen/fuel mixture. The gas or gas mixture then exits the gun forcing the plasma arc outside the gun. A powder is fed into the arc where it is melted and propelled at sonic or higher velocities to the substrate (See Figure 1.2).

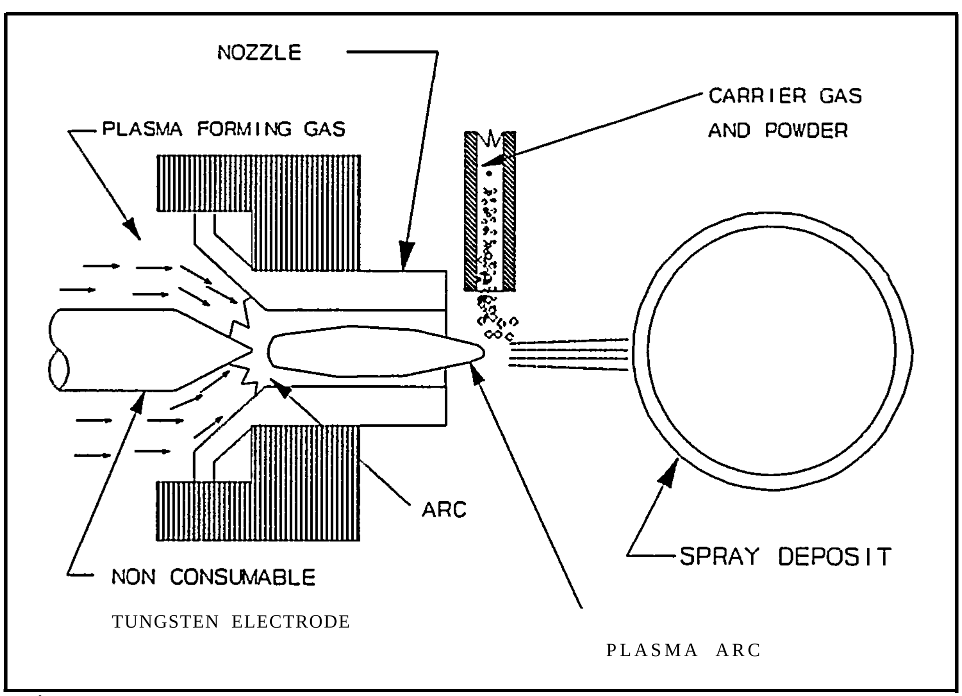

Figure 1.2 PLASMA POWDER PROCESS SCHEMATIC

ARC WIRE PROCESS

The heating zone with the arc wire process forms when an electric arc passes between two continuously fed metallic wires. Compressed air or an inert gas then atomizes and propels the molten material to the substrate (See Figure 1.3).

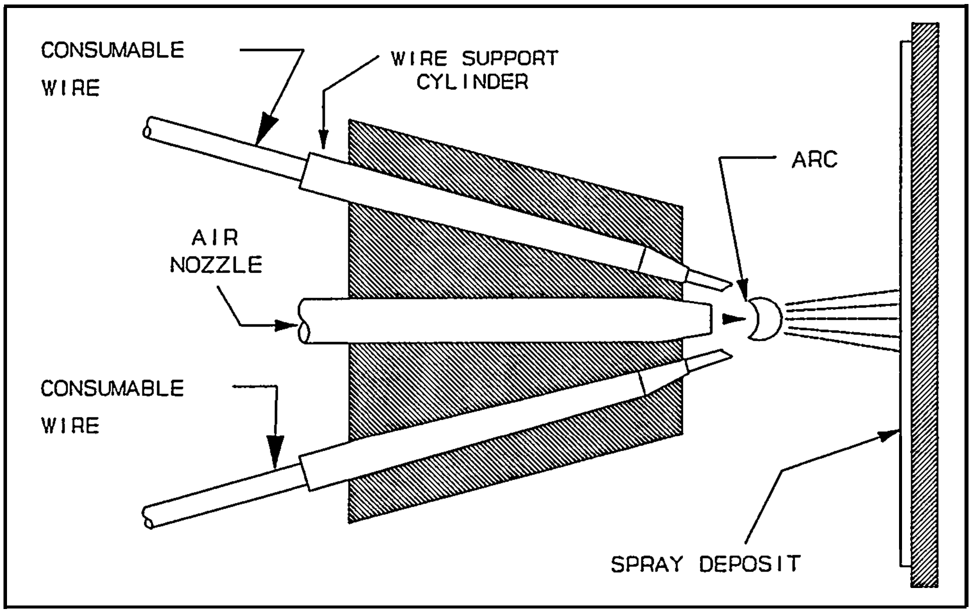

Figure 1.3 ARC WIRE PROCESS SCHEMATIC

FLAME WIRE PROCESS

The flame wire process uses an oxygen/fuel flame to create the heating zone. A wire continuously fed into the heating zone is melted, atomized, and then propelled onto the substrate by the force of the burning gasses and compressed air (See Figure 1.4).

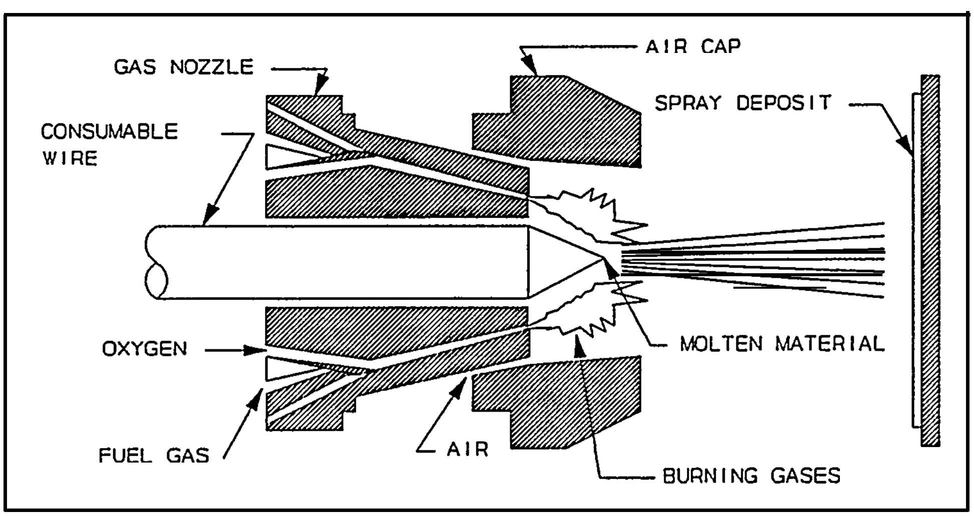

Figure 1.4 FLAME WIRE PROCESS SCHEMATIC

FLAME POWDER PROCESS

The flame powder process uses an oxygen/fuel flame to create the heating zone. Powder enters the heating zone and melts. The molten material is then propelled to the substrate by the force of the burning gasses and compressed air (See Figure 1.5).

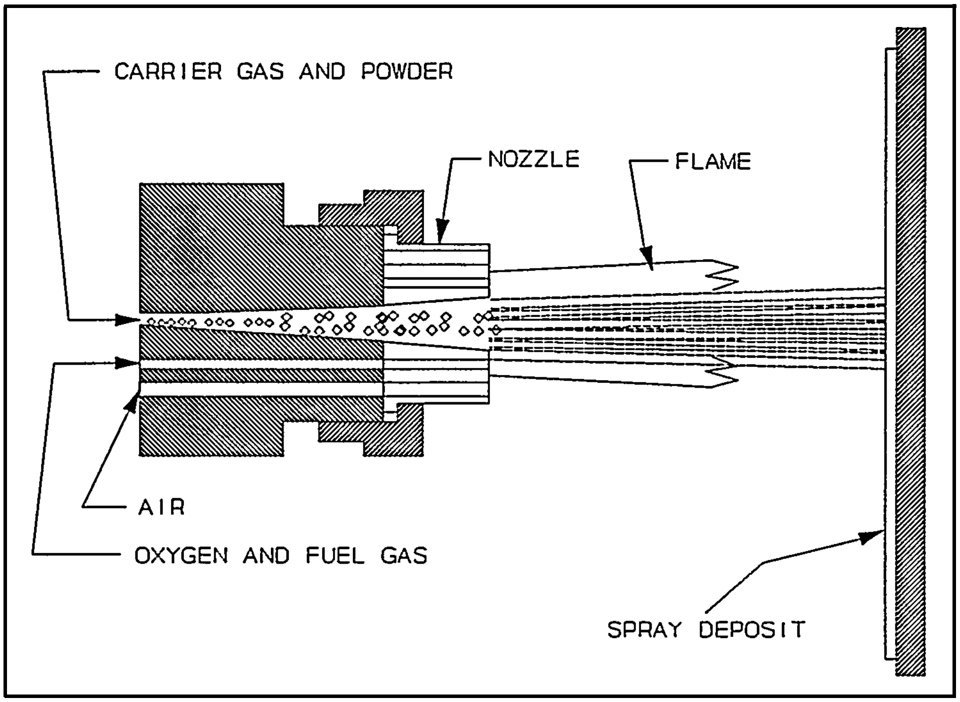

Figure 1.5 FLAME POWDER PROCESS SCHEMATIC

HIGH VELOCITY OXYGEN FUEL (HVOF) PROCESS

The HVOF process is one of the most recently developed of the thermal spray processes. This process uses the combustion of oxygen and fuel (typically propane, propylene, or hydrogen) mixtures at high pressures. This mixture of oxygen and fuel gas bums and is accelerated to supersonic speeds through special shaped nozzles. Thermal spray powder is injected into this constricted flame. The powder then accelerates in the high velocity flame (4500-7000 feet per second) (See Figure 1.6). When the thermal spray material collides with the substrate it plasticizes, flattens and adheres to form a coating. Some of the advantages of this process are due to the fact that it uses relatively low thermal energy coupled with high kinetic energy. This process produces coatings with low porosity, low oxide content, low residual stress, and exceptionally high bond strengths. The HVOF process typically produces coatings with reduced changes in the metallurgical phase composition of the thermal spray material when compared to the other common shipyard thermal spray processes.

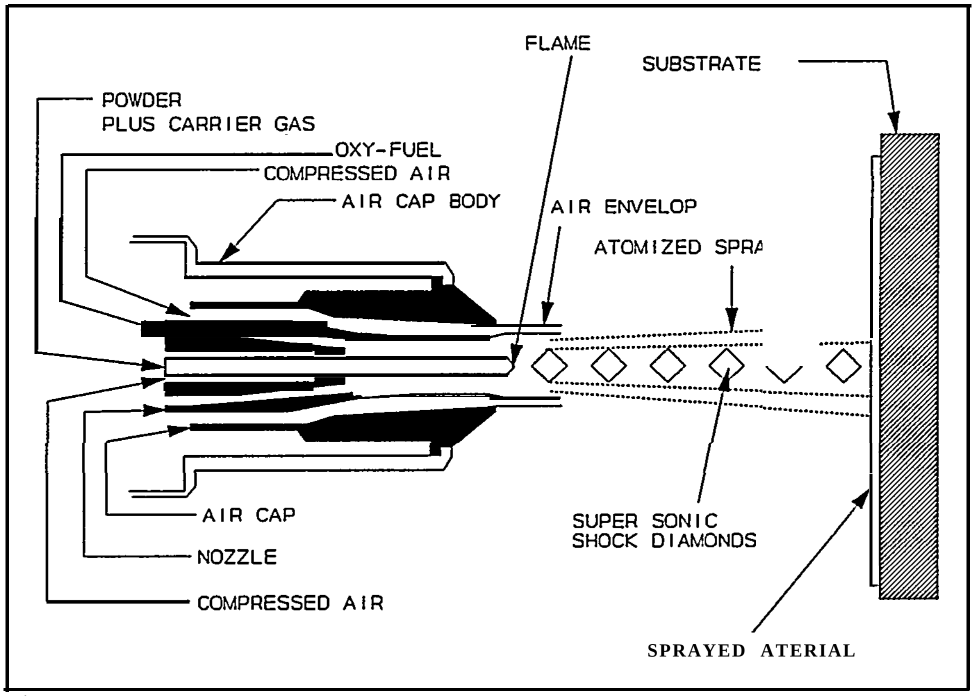

Figure 1.6 HVOF PROCESS SCHEMATIC

FUTURE APPLICATIONS

Around the world, various industries apply the thermal spray process to numerous applications that are not now being fully utilized by shipyards and marine repair facilities. These applications include electromagnetic shielding, thermal barrier coatings, and the thermal spraying of babbitt bearings. New processes and equipment that will provide superior coatings for many future applications are constantly being developed by manufacturers of thermal spray equipment and material.

LIMITATIONS

As with any other repair method, Thermal Sprayed Coatings do have some limitations. Thermal Sprayed Coatings have a significantly lower tensile strength than typical structural materials. Therefore, if undercutting for surface preparation reduces component strength to unacceptable levels, alternative repair or preparation methods must be used. Thermal Sprayed Coatings do not typically stand up to point or line loading, such as would be produced in a ball or roller bearing race. Peening is another example of this type of loading. Any application which seems to fall into this category should either be reconsidered or subjected to laboratory or in-service testing.

CONCLUSION

The Thermal Spiny Process provides many benefits for new and used components. These benefits are capable of producing significant cost savings for ship repair facilities, especially over the long term. Any facilities desiring information or assistance with thermal spray technology can contact the authors of this manual at Puget Sound Naval Shipyard.

SECTION 2

SEQUENCE OF A THERMAL SPRAY JOB

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2 SEQUENCE OF A THERMAL SPRAY JOB

INTRODUCTION

This section provides fundamental information for the sequence of events for using the thermal spray process to repair machinery components. This system is presently used by Naval Shipyards that are authorized by the United States Navy to repair or refurbish machinery components. The following thermal spray system allows Naval Facilities to meet MILITARY STANDARD 1687 (MIL-STD-1687) requirements. This military standard is for thermal spray coating applications for naval machinery and ordnance. This standard is managed and issued by the Naval Sea Systems Command (NAVSEA 03M). The intent of this manual is to help personnel at maritime facilities make sound thermal spray decisions. Note that the sequence phases of the process are described in a brief form for general information only. For complete details please turn to the Manual Section for the process segment of interest.

REASON FOR THERMAL SPRAYING

Thermal sprayed coatings are typically applied to marine machinery components for dimensional restoration or to improve the components performance. Dimensional restoration applications include surface damaged caused by wear, erosion, corrosion, mis-use, or machining errors during the manufacture or repair of a component. The need for dimensional restoration is usually recognized initially by the mechanic reconditioning a system (pump, valve, turbine, etc.) or the system's components (valve stem, pump shaft, turbine rotor shaft, etc.). The mechanic usually contacts the design engineering group to help determine the repair alternatives. The machinist and design engineer meet at the component location and discuss methods of repair or replacement. (To demonstrate the repair sequence system, a damaged 400 Series Stainless Steel pump shaft has been selected. The section to be sprayed is an impeller fit area (See Figure 2. 1).

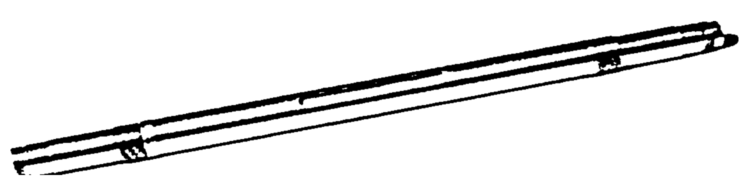


Figure 2.1 400 SERIES STAINLESS STEEL PUMP SHAFT

Since thermal spraying appears to be a good repair method for this component, the design engineer or machinist mechanic contacts the Thermal Spray Shop or the Thermal Spray Engineering group. The Thermal Spray Shop and the Thermal Spray Engineer inspect the damaged component to determine whether the component is repairable using the thermal spray process (See Figure 2.2). For more information see the "Application" Section of this Manual (Section 3).

Figure 2.2 THERMAL SPRAY ENGINEER & THERMAL SPRAY MECHANIC

COATING SELECTION

Once the Thermal Spray Shop and the Cognizant Engineering Group decide that the damaged component is a good candidate for thermal spray repair, a coating selection is made. Selection of the coating system is based on the following elements;

a. Base Material Type
b. Function of Area to be Repaired
c. Service Environment
d. Thermal Spray Coating Material Available
e. Thermal Spray Processes and Equipment Available

To select a thermal spray coating for this 400 Series Stainless Steel Demonstration Shaft, facility personnel used the STAINLESS STEEL ALLOYS Table from the "Coating Selection" Section of this Manual (Section 5). The environment of the packing area is fresh water and the type of section is an impeller fit area. There are four coatings listed in the water fit column of the STAINLESS STEEL ALLOYS Table that could be used to repair the impeller fit area. A ranking is given to each coating system (1 to 4, with 1 as the best selection). If the thermal spray facility has the number one selection material in stock and a plasma powder or flame powder system to apply that material, then the coating system of 21031 is selected.

The other coating systems listed as acceptable could be used if the Eutectic 21031 material is not available. For the purposes of this demonstration pump shaft we shall assume that the thermal spray facility does have the recommended Eutectic material. The ship repair facility that is refurbishing the demonstration pump shaft has plasma powder equipment and a qualified plasma powder procedure for the Eutectic material, so that process is selected to apply the coating. More detailed coating selection information can be located in the “Coating Selection” Section of this manual (Section 5). After the coating selection is made, the Thermal Spray Shop contacts the Design Engineering Group and informs them the component can be repaired with the thermal spray process. The Design Engineer issues a written instruction (Enclosure (2.1)) to the Thermal Spray Shop authorizing the Thermal Spray Shop and the Machine Shop to repair the damaged component.

THERMAL SPRAY JOB CONTROL RECORD (TSJCR)

At this time, the Thermal Spray Shop completes Section I and portions of Section II and III of a Thermal Spray Job Control Record (TSJCR) (Enclosure (2.2)). Record keeping information can be found in the "Quality Assurance Section” of this Manual (Section 9).

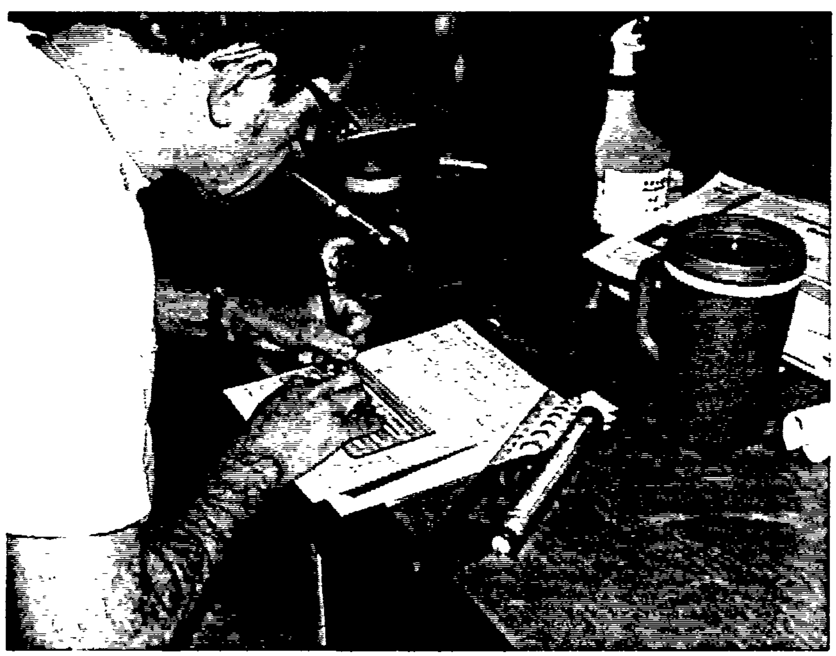


Figure 2.3 OPERATOR FILLING OUT TSJCR

CLEANING

The component is then shipped to the Thermal Spray Shop. For tracking purposes, the TSJCR number is vibratooled onto the component in an area where damage will not be caused to machined surfaces or the service of the component. The component is then cleaned to remove all grease, oil, paint, corrosion products, moisture or any other substance which may contaminate the area that is to be coated. For more detailed information on cleaning see the "Preparing A Machinery Component For Thermal Spraying" Section of this Manual (Section 6).

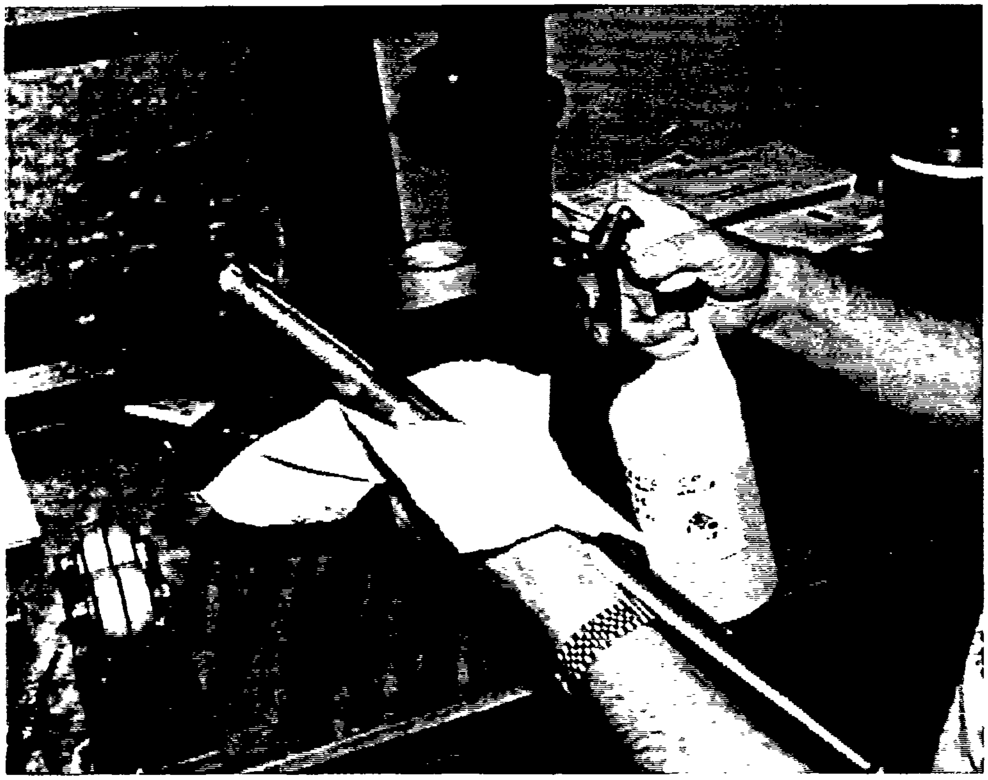


Figure 2.4 CLEANING OF COMPONENT

The bond strength of the coating is extremely dependent on the preparation and cleanliness of the surface to be coated. The application of a coating over a corroded surface must never be attempted. The corrosion products destroy the bond between the coating and the base metal surface. In addition, any moisture that is present in the corrosion product, no matter how minute, will cause further corrosion of the metal and blistering of the coating will occur during service. The metal surface must also be free from contaminants such as oil or grease in order to assure adequate bonding.

UNDERCUTTING

Undercutting allows for a uniform finish coating thickness, removes existing sprayed or plated coatings, and removes damaged or contaminated base metal. In most cases, this step also provides dimensional allowance to permit adequate thermal spray buildup for the application. The TSJCR and the part to be sprayed are sent to the machine shop where the machinist undercuts the component according to the sketch on the TSJCR.

NOTE.	A tapered shoulder should be left at the end of the component whenever possible. A weld bead may be deposited at the end of the component to provide a shoulder, if it causes no mechanical or metallurgical damage to the component. The Welding Engineering Division should be contacted before welding on the machinery component.

After undercutting is completed, component and TSJCR are shipped to the Thermal Spray Shop. The thermal spray operator checks the undercut dimension, list that information on the TSJCR, and cleans the component again. Detailed information on undercutting for thermal spraying can be found in the "Preparing A Machinery Component For Thermal Spraying" Section of this Manual (Section 6).

MASKING

The Thermal Spray Shop masks off areas of the component that may be damaged by surface preparation and/or by thermal spraying. Prior to masking, all oil, grease, rust, scale, paint, or any substance (i.e. anchor tooth blasting) that would inhibit the thermal spray coating from adhering to the substrate must be removed prior to final surface preparation. In order to assure a proper bond, the machinery component should be cleaned of all grease and oil before undercutting, after undercutting, and just before final surface preparation.

FOR ABRASIVE ANCHOR TOOTH BLASTING

Any masking material that gives adequate protection to the substrate and does not cause corrosion or contamination of the sprayed coating or substrate may be used. Following abrasive anchor tooth blasting, any masking material that is unsuitable for production thermal spraying shall be removed and replaced with a suitable masking.

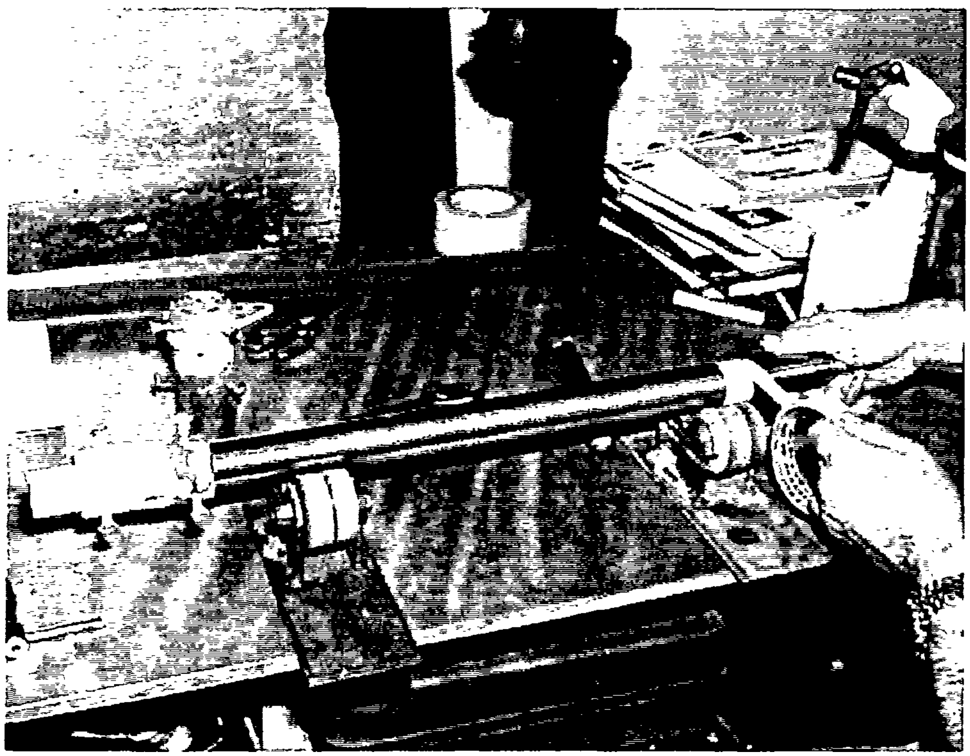
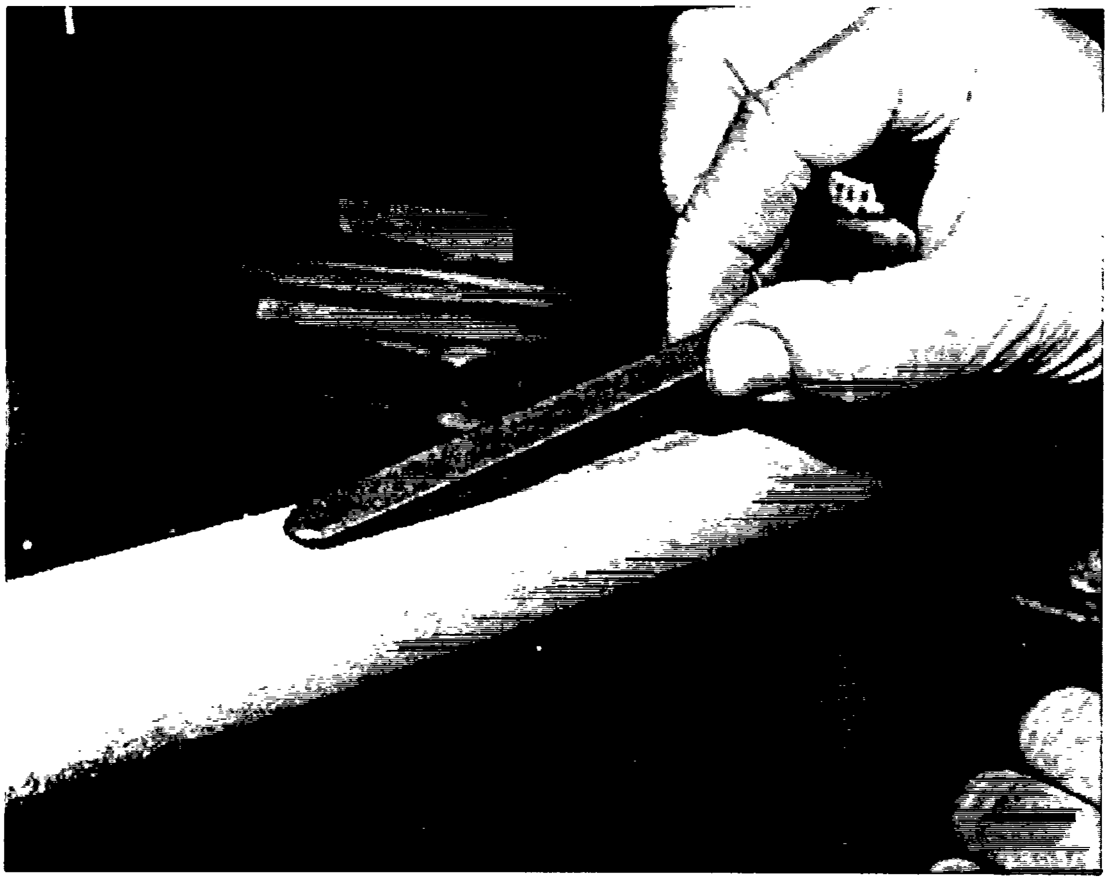


Figure **2.5 MASKING FOR ANCHOR TOOTH BLASTING**

FOR THERMAL SPRAYING

Tapes, liquid masking compounds, silicone rubber or metal shielding may be used as thermal spraying masking materials. Tapes shall be designed for high temperature use. For holes, slots, keyways, or other types of recesses, inserts of carbon or metal may be used. Some types of metal inserts can be left in place during abrasive blasting and spraying, and may be removed after surface finishing. Carbon inserts cannot be used during abrasive blasting, but often serve well for spraying (See Figure 2.6). For more detailed information on masking machinery components for thermal spraying, see the "Preparing A Machinery Component For Thermal Spraying" Section of this Manual (Section 6).



STAGING FOR SPRAYNG

To conserve the time between the surface preparation and the thermal spraying of the component, the operator should set up the thermal spray equipment, measuring equipment (micrometer, contact pyrometer, etc.), and the turning fixture before surface preparation is started (See Figure 2.7). Coating bond quality deteriorates with time delays between anchor tooth blasting and applying the thermal sprayed coating. AH tools that will touch the area to be sprayed after final surface preparation must be cleaned of all oil and grease. When thermal spraying a machinery component for the United States Navy, an approved procedure is required. The parameters used to thermal spray the demonstration component can be found in the "Procedure Qualification" Section of this Manual (Section 11).

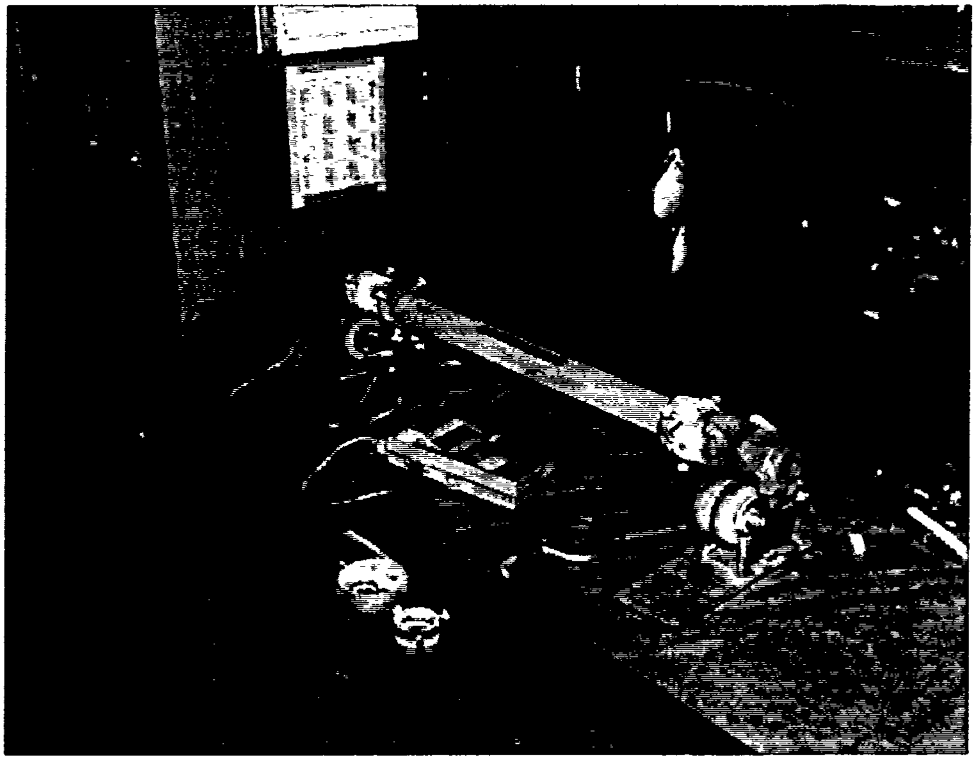


Figure 2.7 STAGING AREA FOR Spraying

SURFACE PREPARATION - ANCHOR TOOTH BLASTING

The thermal spray operator now places the machinery component in a grit blast booth for final surface preparation. The blast booth, as shown in Figure 2.8, should have the capability of creating an anchor-tooth profile of .002" to 0.004" on the surface to be sprayed. To measure the anchor-tooth profile, use profile tape and a specially designed micrometer. The thermal spray operator lists the results of anchor-tooth measurement in the appropriate area on the thermal spray job control record. Aluminum oxide grit is the most commonly used material used by U. S. Naval thermal spray facilities for final surface preparation blasting. Because of the importance of using clean aluminum oxide grit and the criticality of refurbishing machinery components, many facilities use the aluminum oxide grit only once for anchor tooth blasting during final surface preparation. The used grit is then recycled into other blast machines for less critical applications such as corrosion removal. Final surface preparation for thermal spraying machinery components is one of the two most critical steps prior to coating application. Cleanliness and surface roughness of the area to be thermal sprayed have a direct influence on how well the coating adheres to the substrate material.

THERMAL SPRAYING

When final surface preparation is completed, the operator should inspect the component and insure that all areas to be sprayed are 100% grit blasted. This is also the time to repair damaged masking and replace any masks which are unsuitable for thermal spraying (See Figure 2.9). Next, the operator mounts the component in the turning fixture and begins preheating with the plasma gun (if required by the approved procedure) using the parameters set for the bond coat (See Figure 2.10). During the process the anchor tooth area is never handled with bare hands as this can result in deterioration of the coating bond strength. As soon as preheat is completed, the coating is applied, stopping only under certain conditions.

These include measurement of coating thickness or temperature, cool down to prevent overheating, switching to the final coating materials that require a change in parameters, and service of equipment. For more detailed information on thermal spraying, see the "Thernlal Spraying Operation" Section of this Manual (Section 7).

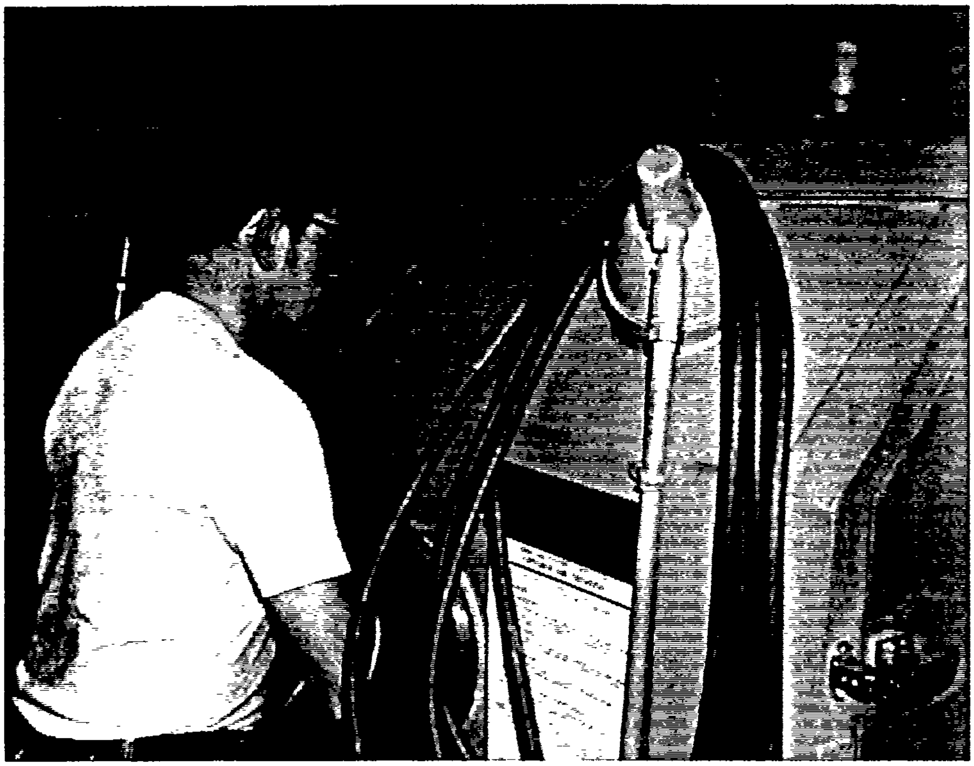


Figure 2.8 GRIT BLASTING OF SHAFT

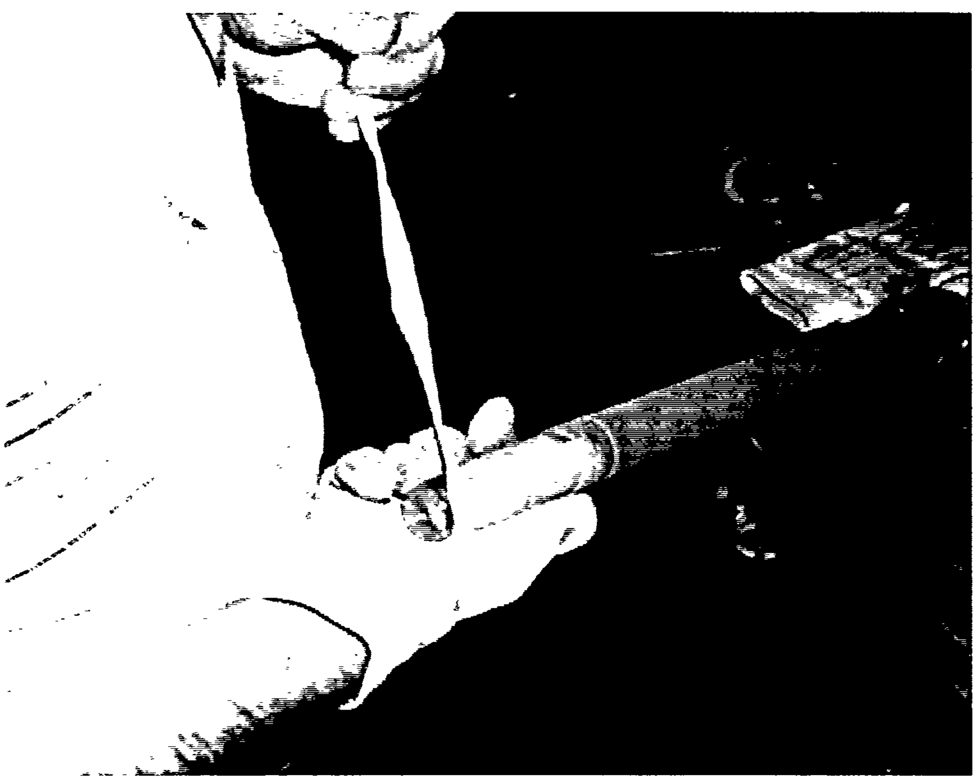


Figure 2.9 MASKING FOR THERMAL SPRAYING

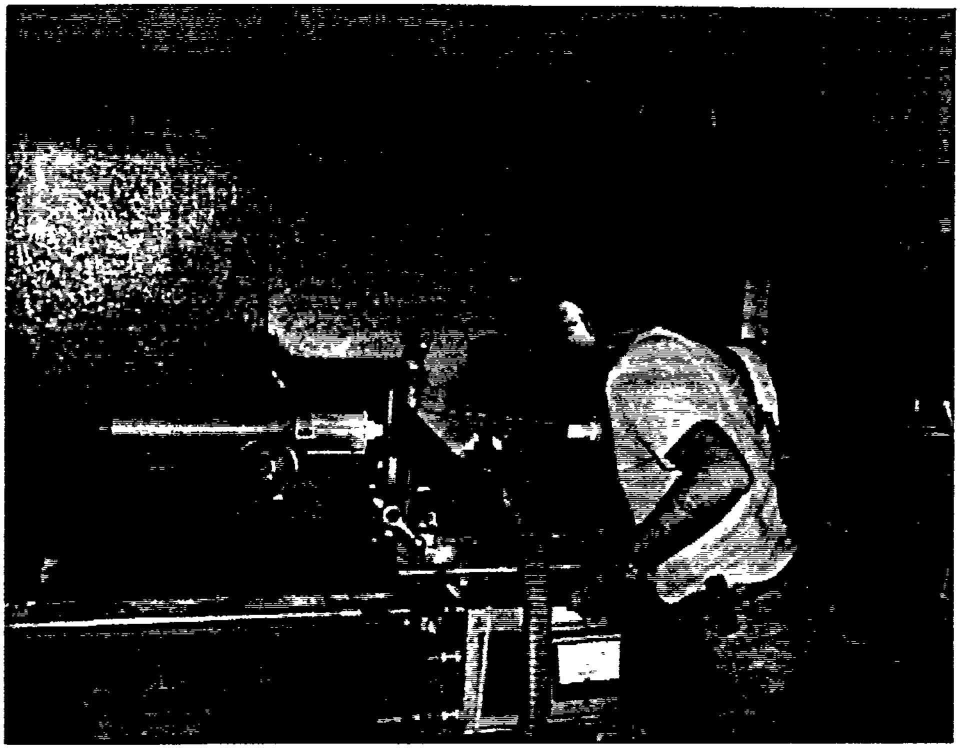


Figure 2.10 PRE HEATING

COOLING & SEALING

When thermal spraying is completed, the operator permits the machinery component to cool. During the cooling cycle, the machinery component should, if practical, be left rotating in the turning fixture to help prevent warpage. While the component is being cooled, the operator may complete Section VII and signs and dates the appropriate area of Section III of the Thermal Spray Job Control Record. When the coating temperature cools to 125° F, a sealer is applied. Phenolic resins in solution are generally used by most ship repair and ship manufacturing facilities. Sealers can be applied by spraying or brushing. More detailed information on cooling and sealing of thermal sprayed machinery components can be found in the "Thermal Spray Operation" Section of this Manual (Section 7)).

DEMASKING

Usually the thermal spray operator removes the masking. This can be done before, after, or during the cooling cycle. Operators must take precautions not to damage the coating while removing the masking.

FINISHING

The machinery component and the Thermal Spray Job Control Record are then sent to the machine shop for finishing. In the case of the demonstration pump shaft, wet grinding was selected as the method of finishing. This is due to the fact that the coating used for the pump shaft required a finish that was unattainable by tooling. Thermal sprayed coatings are routinely machined by wet grinding in lieu of single point tooling.

FINAL INSPECTION

After the machine shop has completed finishing the thermal sprayed coating, the machinery component and Thermal Spray Job Control Record are sent back to the thermal spray operator. A qualified inspector visually inspects and measures the coating. If the coating passes inspection, the foreman or a designated inspector signs and completes the appropriate portion of Section VI of the TSJCR.

Figure 2.11 FINAL INSPECTION

NOTE:	If the coating fails inspection because of a defect, the coating is removed and the component is resprayed.

At this time, the inspector applies the final coat of phenolic sealer. Because the component has low temperature service, a phenolic sealer works well. The component and Thermal Spray Job Control Record are shipped to the installation shop's inspector where it is examined to assure the finish product meets the plan requirements. If the component meets all of the requirements, the inspector signs the appropriate portion of Section VI of the Thermal Spray Job Control Record and ships the Record back to the thermal spray shop. Thermal spray shop personnel check the Thermal Spray Job Control Record for accuracy and completeness and file copies for future reference. The thermal sprayed surface is protected from damage and the component is then sent to the installation mechanic who completes the final task by installing the component.

NOTE:	In some cases, the movement of components and handling of records, as they are sequenced in this chapter, prove to be impractical. When this occurs, the thermal spray shop controls the original Thermal Spray Job Control Record, leaves a copy with the component, and goes to the component whenever practical. This process helps to avoid excessive shipping delays and prevent losses of records and inadvertent damage to thermal sprayed coatings such as ceramics.

IN CONCLUSION

The preceding over site sequence system was developed to enable Naval Shipyards to meet the requirements of MIL-STD-l687 “Thermal Spray Processes for Naval Machinery Applications”. Facilities that are thermal spraying machinery components that are used on other than United States Naval Ships should be able to adapt this sequence system to their own circumstances without any loss of product quality.

ENGINEERING PLANNING INSTRUCTION *	JOB ORDER 81464-90001	KEY-OP 001	REV
HULL	COMPONENT AND TITLE THERMAL SPRAY PUMP SHAFT	ABBREVIATED TITLE	
APL NUMBER	ZONE	LOCATION	CUI

WORK SCOPE

THIS EPI ISSUED TO THERMAL SPRAY REPAIR PUMP SHAFT. PUMP SHAFT IN THE IMPELLER FIT AREA IS SCORED.

SPECIAL WORK CONSIDERATIONS

OBJECTIVE QUALITY EVIDENCE REQD
REPORTS REQUIRED

SUMMARY

TASK ID	SHOP	MHRS	STD
01	31	Ml	4
02	26	W4	6
03	31	Ml	6

MATERIAL	EPID	FUNDS AUTHORIZATION
100		1213.8-8146446-0140

REVIEW

PLANNING (SIGNATURWCODE)	TECHNICAL (SIGNATUREICODE)	BRANCH MANAGER (SIGNATURE/CODE)

DISTRIBUTION

COPIES' TO: 1213,246,362, 133, 136,224,
260.27,
260.24

ROUTING

CODE	260.27	260.24	260.2	
INITIALS				
DATE				

This instruction is initiated by engineering or planning personnel. For repeat/routine work this instruction may eliminated.

EPI TASK WORK PERMIT/AUTHORIZATION	JOB ORDER 81464-90001	KEY -OP 001	TASK ID 01	TASK REV -
HULL	TASK DESCRIPTION MACHINE PUMP SHAFT		ABBREVIATED TITLE TSR SHAFT	
SYSTEM	ZONE NA	LOCATION S/31	PHASE	CUI
SHOP 31	TSD M1	MAN HORS 4	MAN-HRS REV	STANDARD
PLANNER SHANNON	6-3288	CODE 260.27	BORTVEDT	6-2995
WORK AUTHORIZATION				
SSO/SSS			DATE	
SF CONCURRENCE			DATE	
WTC APPROVAL TO PROCEED WITH WORK			DATE	
TASK/CLOSURE CERTIFICATION				
MECHANIC (SIGNATURE)	SUPERVISOR (SIGNATURE)/DATE		SHOP/CODE	BADGE
1. Mechanics signature certifies understands and completion of technical direction.	2. Supervisor's signature certifies completion of task.		3. Send certified copy to Code 246.3.	
WORK CONTROL COMPLETION				
SHIPS FORCE			DATE	
WTC			DATE	
SPECIAL CONSIDERATIONS				
OBJECTIVE QUALITY EVIDENCE REQD				
TECHNICAL DIRECTION				

REF: A. MNP 13577 REV B PUMP SHAFT
B. PROCESS INSTRUCTION "THERMAL SPRAY MACHINE REPAIR"

<1> MACHINE PUMP SHAFT, TO TSJCR No 110-95, AT 1.345" ± 0.005" DIAMETERS TO REMOVE DAMAGED AND SCORED SURFACES. MACHINE TO BE PER REF (B) PARA 6.2.2.1.

<2> ENTRY ANGLES TO REDUCED SHAFT DIAMETERS TO BE AT 45 DEGREES, PROVIDE .015/.020" RADIUS AT CORNERS OF UNDERCUT. SHAFT SHOULDERS TO BE PER REF (B) PARA. 6.2.2.3. DO NOT REDUCE SHAFT DIAMETERS WITHIN 1/8" OF THE END OF THE SHAFT.

<3> AT COMPLETION OF MACHINING FORWARD PREPARED PUMP SHAFT TO SHOP 26 THERMAL SPRAY FACILITY, BUILDING 460.

EPI TASK WORK PERMIT/AUTHORIZATION	JOB ORDER 81464-90001	KEY -OP 001	TASK ID 01	TASK REV -
HULL	TASK DESCRIPTION THERMAL SPRAY PUMP SHAFT		ABBREVIATED TITLE TSR SHAFT	
SYSTEM	ZONE NA	LOCATION S/31	PHASE	CUI
SHOP 26	TSD W4	MAN HORS 6	MAN-HRS REV	STANDARD
PLANNER SHANNON	6-3288	CODE 260.27	BORTVEDT	6-2995
WORK AUTHORIZATION				
SSO/SSS			DATE	
SF CONCURRENCE			DATE	
WTC APPROVAL TO PROCEED WITH WORK			DATE	
TASK/CLOSURE CERTIFICATION				
MECHANIC (SIGNATURE)	SUPERVISOR (SIGNATURE)/DATE		SHOP/CODE	BADGE
1. Mechanics signature certifies understands and completion of technical direction.	2. Supervisor's signature certifies completion of task.		3. Send certified copy to Code 246.3.	
WORK CONTROL COMPLETION				
SHIPS FORCE			DATE	
WTC			DATE	
SPECIAL CONSIDERATIONS				
OBJECTIVE QUALITY EVIDENCE REQD				
TECHNICAL DIRECTION				

REF: A. MNP 13577 REV B PUMP SHAFT
B. PROCESS INSTRUCTION "THERMAL SPRAY MACHINE REPAIR"

<1> RECEIVE PUMP SHAFT, REF (A) FROM SHOP 31 (MACHINE SHOP) AT COMPLETION OF PRELIMINARY MACHINING.

<2) ACCOMPLISH REF (B) PARA. 6.2.3 AND 6.2.5 SPECIFIED MASKING AND ANCHOR TOOTH BLASTING.

<3> THERMAL SPRAY PUMP SHAFT TO PROVIDE SUFFICIENT BUILDUP FOR FINISH MACHINING. PUMP SHAFT MATERIAL IS 400 CRES. PER CODE 138 RECOMMENDATION THERMAL SPRAY COATING TO BE EUTECTIC 21031.

<4> AT COMPLETION OF THERMAL SPRAYING FORWARD PREPARED PUMP SHAFT TO SHOP 31 FOR FINISH MACHINING.

EPI TASK WORK PERMIT/AUTHORIZATION	JOB ORDER 81464-90001	KEY -OP 001	TASK ID 01	TASK REV -
HULL	TASK DESCRIPTION FINISH MACHINE PUMP SHAFT		ABBREVIATED TITLE TSR SHAFT	
SYSTEM	ZONE NA	LOCATION S/31	PHASE	CUI
SHOP 31	TSD M1	MAN HORS 6	MAN-HRS REV	STANDARD
PLANNER SHANNON	6-3288	CODE 260.27	BORTVEDT	6-2995

WORK AUTHORIZATION

SSO/SSS	DATE
SF CONCURRENCE	DATE
WTC APPROVAL TO PROCEED WITH WORK	DATE

TASK/CLOSURE CERTIFICATION

MECHANIC (SIGNATURE)	SUPERVISOR (SIGNATURE)/DATE	SHOP/CODE	BADGE
1. Mechanics signature certifies understands and completion of technical direction.	2. Supervisor's signature certifies completion of task.	3. Send certified copy to Code 246.3.	

WORK CONTROL COMPLETION

SHIPS FORCE	DATE
WTC	DATE

SPECIAL CONSIDERATIONS

OBJECTIVE QUALITY EVIDENCE REQD

TECHNICAL DIRECTION

REF: A. MNP 13577 REV B PUMP SHAFT

<1> FINISH MACHINE/GRIND THERMAL SPRAY BUILDUP AREAS TO FINISH SIZE OF 1.372" ±.001". MACHINING/GRINDING TO BE CONCENTRIC TO BEARING DIAMETERS WITHIN .001". SURFACE FINISH TO BE 64 RHR MINIMUM.

<2) UPON COMPLETION OF FINISH MACHINING/GRINDING CONTACT SHOP 26 FOR FINAL COATING INSPECTION AND APPLICATION OF SURFACE SEALER. SEALER TO BE METCO AP.

THERMAL SPRAY JOB CONTROL RECORD (TSJCR)

SERIAL No. 110-95

REF MIL-STD-1687

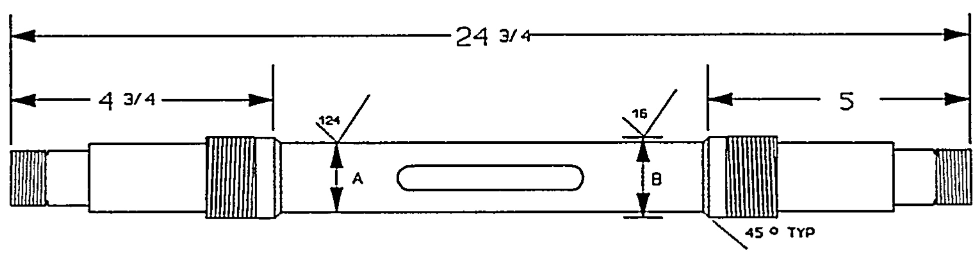
SECTION I JOB DATA

JOB ORDER NUMBER: 81464-90001-000	SHIP/PROJECT: USS THERMAL SPRAY MANUAL	OPERATING MEDIUM: WATER
FOREMAN/SHOP: TRAVIS/138	PHONE: 360-476-2469	MECHANIC/SHOP: GINTHER/SHOP 26 — PHONE: 8812
PART DESCRIPTION: PUMP SHAFT	DRAWING NO.: 88878C-29341349-52	PC. NO.: 8
FUNCTION OF COATING: IMPELLER FIT AREA	BASE MATERIAL/ALLOY/MIL SPEC/ETC: 400 SERIES CRES	SCHED COMPL DATE:
REASON FOR SPRAYING: SCORING	SHIP SYSTEM: FRESH WATER	

SECTION II PREPARATION

1. PROVIDE CENTERS BOTH ENDS
2. UNDERCUT AND FINISH ON SAME CENTERS CONCENTRIC TO AREAS C AND D WITHIN .001"
3. REMOVE MINIUM AMOUNT OF MATERIAL NECESSARY TO REMOVE SURFACE DAMAGE
4. MAX TAPER OF UNDERCUT .002"

UNDERCUT DIAMETER "A"	1.345	±0.005
ACTUAL DIA "A"	1.344	
(FINISH) DIA "B"	1.372	±0.001



SECTION III SPRAYING SHOP

PROCEDURE I.D. (APP OR MWP#): APP#9	SEALER TYPE: AP
BOND COAT MATERIAL/PROCESS: N/A	
FINISH COAT MATERIAL/PROCESS: EUTECTIC 21031/PLASMA POWDER	
S/26 OPERATOR (SIGNATURE)	DATE
S/26 FOREMAN (SIGNATURE)	DATE

SECTION IV APPROVALS

AUTHORIZING DOCUMENT IDENTIFICATION: MIL-STD-1687A

SECTION V FINAL MACHINING

FINAL MACHINING TOOLING USED: GRIND ☐ TOOLING ☐

SECTION VI VERIFICATION SIGNATURES

1. TSJCR UNDERCUT INSTRUCTIONS MEET EPI REQUIREMENTS	(Signature)(S/31)	DATE
2. MACHINED PREPARATION IS IN ACCORDANCE WITH SKETCH	(Signature)(S/26)	DATE
3. INSPECTION OF FINISHED SURFACE (RESULTS FOUND IN SECTION VIII)	(Signature)(S/26)	DATE
4. FINISHED SURFACE CONDITION MEETS PLAN REQ. FOR SIZE, SURFACE COND.	(Signature)(Lead Shop)	DATE

SECTION VII SPRAY DATA

METHOD OF SURFACE PREPARATION
- ☐ ALUMINUM OXIDE BLASTING
- ☐ THREADING
- ☐ OTHER (SPECIFY): ________

ANCHOR TOOTH HEIGHT (MILS) 3.3

BOND COATING THICKNESS APPLIED N/A

FINISH COATING THICKNESS APPLIED .028

TOTAL COATING THICKNESS APPLIED .028

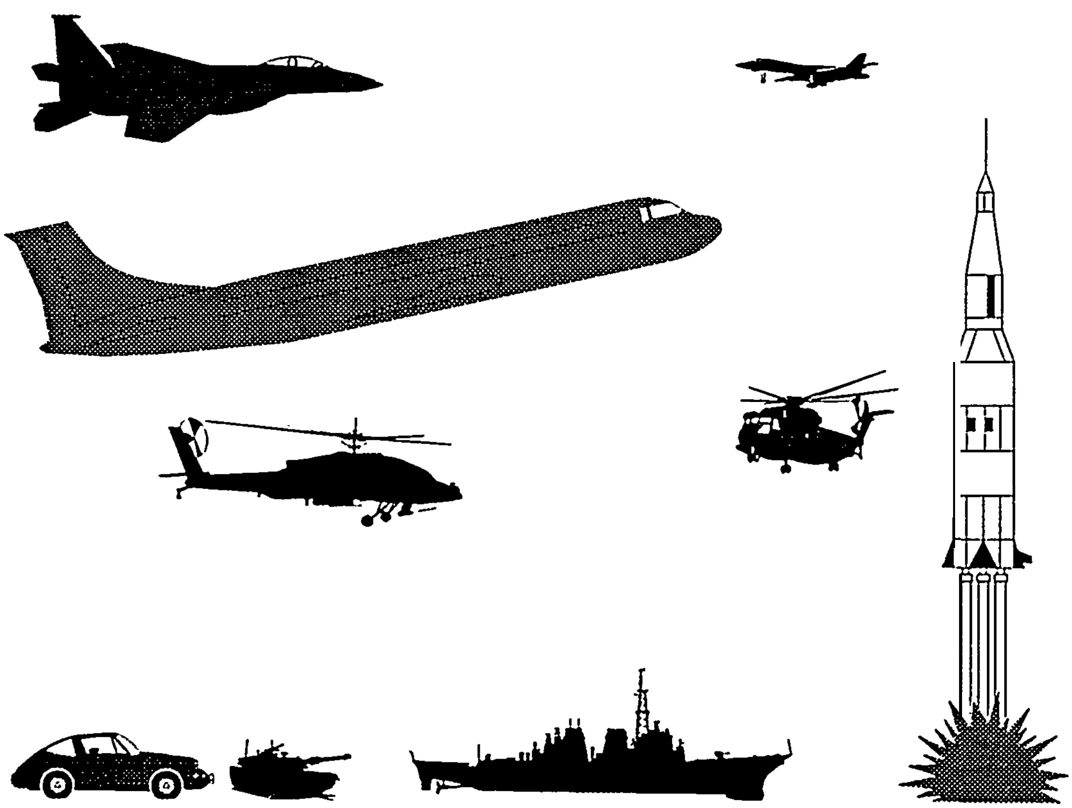
SECTION VIII INSPECTION

INSPECTION METHODS USED:
- ☐ VISUAL ☐ SAT ☐ UNSAT
- ☐ DIMENSION ☐ SAT ☐ UNSAT
- ☐ THERMAL WAVE NDE ☐ SAT ☐ UNSAT
- ☐ OTHER (SPECIFY):________ ☐ SAT ☐ UNSAT

ACCEPTANCE STANDARD:
☐ PROCESS INSTRUCTION ☐ OTHER (SPECIFY):________ REMARKS:

SECTION 3

THERMAL SPRAY APPLICATIONS



PREPARED BY: PUGET SOUND NAVAL SHIPYARD

3 APPLICATIONS

THERMAL SPRAY APPLICATIONS

INTRODUCTION

Thermal spraying is typically performed to restore the dimensions of a machinery component and to a lesser degree to improve surface performance. Some reasons for dimensional restoration include wear, erosion, corrosion or mismachining. Most of the machinery components repaired by this process are shafts. Some ship building and ship repair facilities have used the thermal spray process to repair inside bores. Other thermal spray facilities have repaired mating surfaces of pump casings and babbitt bearings.

HISTORY

Before the Naval Sea Systems Command would permit the use of the thermal spray process on shipboard components, testing was completed to determine the reliability and effectiveness of the process as a repair method for critical machinery components. The Naval Sea System Command; the Naval Surface Warfare Center Annapolis, Maryland (formerly David Taylor Naval Ship Research and Development Center); and Puget Sound Naval Shipyard developed a program to assess the performance of new thermal spray coatings and techniques and to review past industrial applications. To determine the reliability of ships machinery thermal spray applications, the following four-pronged approach was developed:

1. Compile and evaluate case histories of thermal sprayed components.
2. Perform thermal spray coating laboratory and procedure qualification testing.
3. Perform land based service testing of thermal sprayed components.
4. Perform fatigue, wear, corrosion, and shock testing of thermal spray machinery components.

CURRENT APPLICATIONS

Because the above. four-pronged program was highly successful, the Naval Sea System Command approved thermal spray applications on many critical machinery components. The Naval Sea System Command's Military Standard 1687 covers the thermal spray processes for repair and overhaul of naval ship machinery and ordnance components. Permitted applications on surface ships presently include main feed pumps, forced draft blowers, and other equipment of equal or lesser criticality. One good example of a Naval Sea Systems Command approved application is the thermal spraying of 410 stainless steel steam valve stems. Steam valve stems have been approved for thermal spraying, because of the cost savings obtained (approximately $1,000.00 per stem) by repairing the stems instead of purchasing or manufacturing new ones. The coating system used to repair these components is a plasma sprayed bond coating of Eutectic 21031 (Nickel, Chromium, Molybdenum & Aluminum) and a plasma sprayed ceramic final coat of Metco 143 (Zirconia, Titania & Yttria). Frequently these thermal sprayed coatings perform better than new components. Thermal sprayed ceramic stems have superior stagnant fresh water and sea-water corrosion resistance.

Other approved repairs on machinery components include:

1. Repair of static fit areas to restore orginal dimensions, finish, and alignment.
2. Repair of seal (including packing) areas to restore original dimensions and finish.
3. Repair of fit areas on shafts to restore original dimensions and finish (except for motor generator sets).
4. Buildup on pump shaft sleeves and wear rings to restore original dimensions.
5. Repair of bearing shaft journals to restore original dimensions.
6. Babbitt bearings for auxiliary equipment.
7. Turbine pump casing flanges to restore original dimensions.
8. Ceramic for corrosion/erosion protection.
9. Exposed areas on shafts to restore surface finish requirements.
10. Ceramic to overcome galling tendencies of current designs.

On United States Navy Ships, applications not specified in Military Standard 1687 require Naval Sea Systems Command approval for each item to be sprayed. That approval should be based on the results of laboratory or service tests to determine the adequacy of using the thermal spray process in the proposed application.

TABLE 3.1 has been created to list some of the types of components which have been repaired by using the therrmal spray process. This list of components was obtained from the data base that is kept by the Naval Surface Warfare Center in Annapolis, Maryland. All of the machinery components listed are known successful thermal spray applications performed by Puget Sound Naval Shipyard, Naval Intermediate Maintenance Activities (IMAs), the Naval Shore Repair Facility (SRI) Guam, and private ship repair facilities.

CONCLUSION

In addition to the various types of components currently in service, the potential exists for many new thermal spray applications on military and commercial vessels. Manufacturers produce a wide variety of thermal spray materials to meet the needs of many applications. TABLE 3.2 list a broad range of current and potential applications for which coating materials exist. It is important to note that many of the applications suggested by this table go far beyond the current limits of MIL-STD-1687 approval.

TABLE 3.1

CURRENT APPLICATIONS

COMPONENT	SHIPS SYSTEM	AREA REPAIRED	**BASE MATERIAL**	ENVIRONMENT	* PROCESS	THERMAL SPRAY MATERI
FORCE DRAFT BLOWER SHAFT	FORCE DRAFT BLOWER	LABYRINTH SEAL	CARBON STEEL	STEAM	FINAL PP	EUTECTIC 21031
PUMP SHAFT	CONTAMINATED HOLDING TANK	PACKING	NiCu	SALT WATER	BOND PP	DRESSER PP-25
					FINAL PP	METCO 130
WORM SHAFT	LUBE OIL	SEAL	CARBON STEEL	FUEL OIL	FINAL PP	METCO 444
ROTOR SHAFT	PUMP MOTOR	JOURNAL	NiCu	FRESH WATER	FIINAL PP	DRESSER P-25
VALVE STEM	MAIN STOP VALVE	PACKING	410 STAINLESS STEEL	STEAM	BOND PP	EUTECTIC 21031
					FINAL PP	METCO 130
SHAFT SLEEVE	CIRCULATING PUMP	PACKING	K-MONEL	SALT WATER	BOND PP	DRESSER PP-25
					FINAL PP	METCO 130
VALVE STEM	MS-9 VALVE	PACKING	410 STAINLESS	STEAM	BOND PP	EUTECTIC 21031
					FINAL PP	METCO 143
PUMP SHAFT	SALT WATER COOLING	FIT	NiCu	SALT WATER	FINAL PP	DRESSER PP-25
VALVE FLANGE	RELIEF VALVE	FLANGE	BRONZE	SALT WATER	FINAL FW	METCO SPRAYBRONZE AA
PUMP SHAFT	DISTILLATION	JOURNAL	NiCu	FRESH WATER	FINAL FP	DRESSER PP-25

* AW = ARC WIRE PROCESS
FW = FLAME WIRE PROCESS
PP = PLASMA POWDER PROCESS
FP = FLAME POWDER PROCESS

TABLE 3.1

CURRENT APPLICATIONS

COMPONENT	SHIPS SYSTEM	AREA REPAIRED	BASE MATERIAL	ENVIRONMENT	PROCESS	THERMAL SPRAY MATERIAL
END BELL	PUMP MOTOR	EDGE	CAST IRON	SALT WATER	FINAL PP	EUTECTIC 21031
MOTOR SHAFT	AC MOTOR	FIT	CARBON STEEL	AIR	FINAL PP	METCO 444
PUMP SHAFT	LUBE OIL	SEAL	CARBON STEEL	LUBE OIL	FINAL PP	METCO 443
SHAFT	MAIN FEED BOOSTER	SEAL	CARBON STEEL	SALT WATER	BOND PP	EUTECTIC 21031
					FINAL PP	METCO 130
STRAINER PLUG	SALT WATER CIRCULATION	OUTSIDE DIAMETER	BRONZE	SALT WATER	FINAL AW	METCO SPRAYBRONZE AA
STRAINER PLUG	SALT WATER CIRCULATION	OUTSIDE DIAMETER	BRONZE	SALT WATER	FINAL FW	METCO SPRAYBRONZE AA
STRAINER PLUG	LUBE OIL	OUTSIDE DIAMETER	BRONZE	LUBE OIL	FINAL FW	METCO SPRAYBRONZE AA
TURBINE ROTOR SHAFT	AUXILIARY STEAM	PACKING	CARBON STEEL	STEAM	BOND PP	METCO 443
					FINAL PP	METCO 130
TURBINE ROTOR SHAFT	AUXILIARY STEAM	BEARING JOURNAL	CARBON STEEL	OIL	BOND PP	METCO 443
					FINAL PP	METCO 130

* AW = ARC WIRE PROCESS
FW = FLAME WIRE PROCESS
PP = PLASMA POWDER PROCESS
FP = FLAME POWDER PROCESS

TABLE 3.1

CURRENT APPLICATIONS

COMPONENT	SHIPS SYSTEM	AREA REPAIRED	BASE MATERIAL	ENVIRONMENT	* PROCESS	THERMAL SPRAY MATERIAL
END BELL	VENTILATION SYSTEM	BEARING JOURNAL	CARBON STEEL	AIR	FINAL FP	METCO 444
PLUG	DUPLEX STRAINER	OUTSIDE DIAMETER	BRASS	SALT WATER	BOND FW	METCO 405
					FINAL FW	METCO SPRAYBRONZE AA
STUB SHAFT	MAIN PROPULSION	SEAL	BRONZE	SALT WATER	BOND PP	METCO 445
					FINAL PP	METCO 130
DONKEY BOILER	RECIRCULATING PUMP	PACKING	CARBON STEEL	CONDENSATE STEAM	FINAL PP	EUTECTIC 21031
VALVE STEM	MAIN FEED PUMP GOVERNOR	PACKING	STAINLESS STEEL	STEAM	BOND PP	EUTECTIC 21031
					FINAL PP	METCO 143
ROTOR SHAFT	CONTAMINATED HOLDING TANK	IMPELLER FIT	NiCu	SEWAGE/ WASTE	FINAL PP	DRESSER PP-25
PUMP PLUNGER	BRINE PUMP	PACKING	STAINLESS STEEL	BRINE	BOND PP	METCO 444
					FINAL PP	METCO 136F
BEARING HOUSING	BALLAST PUMP	INSIDE DIAMETER	BRONZE	GREASE	FINAL PP	METCO 445

* AW = ARC WIRE PROCESS
FW = FLAME WIRE PROCESS
PP = PLASMA POWDER PROCESS
FP = FLAME POWDER PROCESS

TABLE 3.1

CURRENT APPLICATIONS

COMPONENT	SHIPS SYSTEM	AREA REPAIRED	BASE MATERIAL	ENVIRONMENT	* PROCESS	THERMAL SPRAY MATERIAL
BABBITT BEARING SHELL	LUBE OIL PUMP	OUTSIDE DIAMETER	CARBON STEEL	AIR	FINAL PP	METCO 447
EXPANSION JOINT	CATAPULT STEAM	PACKING	CuNi	STEAM	BOND PP	EUTECTIC 21021
					FINAL PP	METCO 130
BABBITT BEARING	TURBINE GENERATOR	INSIDE DIAMETER	BABBITT	OIL	FINAL AW	BABBITT
PLUNGER	AIRCRAFT ELEVATOR	OUTSIDE DIAMETER	CARBON STEEL	GREASE	FINAL AW	METCO METCOLOY #2
FLOW SERVICE PUMP	FUEL OIL	PACKING	CARBON STEEL	FUEL OIL	BOND PP	METCO 447
					FINAL PP	METCO 130
POTABLE WATER MOTOR SHAFT	POTABLE WATER	JOURNAL	NiCu	POTABLE WATER	FINAL PP	DRESSER PP-25
ROTOR SHAFT	WATER PUMP	PACKING	CARBON STEEL	FRESH WATER	BOND PP	METCO 447
					FINAL PP	METCO 130
MOTOR SHAFT	MOGAS PUMP	FIT	CARBON STEEL	AIR	FINAL PP	METCO 444
ROTOR SHAFT	SALT WATER COOLING PUMP	PACKING	NiCu	SALT WATER	BOND PP	DRESSER PP-25
					FINAL PP	METCO 130

* AW = ARC WIRE PROCESS
FW = FLAME WIRE PROCESS
PP = PLASMA POWDER PROCESS
FP = FLAME POWDER PROCESS

TABLE 3.1

CURRENT APPLICATIONS

COMPONENT	SHIPS SYSTEM	AREA REPAIRED	BASE MATERIAL	ENVIRONMENT	* PROCESS	THERMAL SPRAY MATERIAL
ROTOR SHAFT	VENTILATION	FIT	CARBON STEEL	AIR	FINAL PP	METCO 447
PUMP SHAFT	SSTG PUMP	FIT	CARBON STEEL	AIR	FINAL PP	METCO 444
HD-977 SP PUMP SHAFT	SP-5-49 COOLING	SEAL	NiCu	SALT WATER	BOND PP	DRESSER PP-25
					FINAL PP	METCO 130
PUMP SHAFT	ELECTRONIC COOLING	SEAL	NiCu	FRESH WATER	BOND PP	DRESSER PP-25
					FINAL PP	METCO 130
PUMP CASING	FIRE PUMP	INSIDE DIAMETER (BEARING JOURNAL FIT)	CARBON STEEL	OIL	FINAL AW	TAFA 75B
PUMP SHAFT	CHILL WATER PUMP	FIT	NiCu	AIR	FINAL AW	EN-60
THRUST ROLLER PLUNGER	AIRCRAFT ELEVATOR		CARBON STEEL	GREASE	FINAL AW	METCO METCOLOY #2
PLUNGER	AIRCRAFT ELEVATOR	SEAL	CARBON STEEL	GREASE	BOND PP	METCO 444
					FINAL PP	METCO 130

* AW = ARC WIRE PROCESS
FW = FLAME WIRE PROCESS
PP = PLASMA POWDER PROCESS
FP = FLAME POWDER PROCESS

TABLE 3.1

CURRENT APPLICATIONS

COMPONENT	SHIPS SYSTEM	AREA REPAIRED	BASE MATERIAL	ENVIRONMENT	* PROCESS	THERMAL SPRAY MATERIAL
PISTON ROD	AIRCRAFT ELEVATOR	SEAL	CARBON STEEL	AIR	BOND PP	METCO 447
					FINAL PP	METCO 130
STEAM VALVE STEM	CATAPULT	PACKING	410 STAINLESS STEEL	STEAM	BOND PP	METCO 444
					FINAL PP	METCO 143
IMPELLER	CATAPULT	FIT	GUN METAL BRONZE		FINAL AW	AMPCO 10
PUMP SHAFT	EMERGENCY DIESEL	PACKING	STAINLESS STEEL		BOND PP	METCO 447
					FINAL PP	METCO 130
ROTOR SHAFT	DEFUELING PUMP	FIT	NiCu	OIL	FINAL AW	EN-60
RETRACT SHEAVE SHAFT	ARRESTING GEAR	FIT	CARBON STEEL	STEAM	FINAL PP	METCO 447

AW = ARC WIRE PROCESS
FW = FLAME WIRE PROCESS

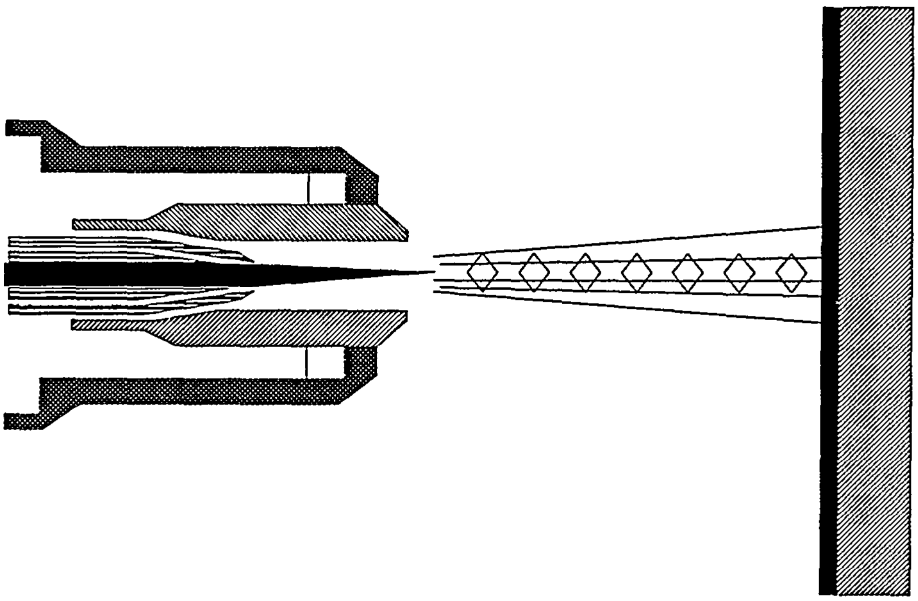
PP = PLASMA POWDER PROCESS
FP = FLAME POWDER PROCESS

TABLE 3.2	
POTENTIAL THERMAL SPRAY APPLICATIONS	
GENERAL APPLICATIONS	SPECIFIC CONDITIONS
WEAR RESISTANCE	SOFT BEARINGS HARD BEARINGS ABRASIVE RESISTANT FIBER/THREAD CAVITATION PARTICLE EROSION
HEAT & OXIDATION RESISTANCE	OXIDIZING ATMOSPHERES CORROSIVE GASES THERMAL BARRIERS MOLTEN METAL HANDLING
CORROSION RESISTANCE	INDUSTRIAL & SALT ATMOSPHERE FRESH WATER SALT WATER CHEMICAL & FOOD PROCESSING
ELECTRICAL	CONDUCTIVE RESISTORS INSULATORS RADIO FREQUENCY SHIELDING
RESTORATION OF DIMENSIONS	MACHINABLE MATERIALS GRINDABLE MATERIALS VAR1OUS ALLOYS
MACHINE ELEMENT CLEARANCE CONTROL	ABRADABLE COATINGS ABRASIVE COATINGS
CHEMICAL CORROSION RESISTANCE	METAL COATINGS CERAMIC COATINGS CERMETS PLASTICS

The thermal spray materials tabulated in this manual have been so listed because of the experience Naval facilities have had using these manufacturers in the past. It is to be noted that other companies also produce excellent quality and equivalent thermal spray materials.

SECTION 4

THERMAL SPRAYING PROCESSES



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4 THERMAL SPRAYING PROCESSES

INTRODUCTION

The primary thermal spray processes being used by the marine repair industry are the plasma powder, arc wire, flame wire, high velocity oxygen fuel, and flame powder processes.

PROCESS SELECTION

When choosing a thermal spray process for a specific application, numerous factors which affect quality and productivity must be compared. This can become a complex decision due to the number of conflicting advantages and limitations which each process may possess for a given situation. Each process can be ranked in terms of its deposition rate in pounds of thermal spray material deposited per hour. However, there are other factors which must be considered. For instance, a new process may have a high deposition rate, but may require extensive training and research and development for procedure qualifications. With some processes, the cost to set up in a field situation may be prohibitive. Process selection should be based on personnel skill and their knowledge of available processes. Many factors must be taken into account for the best process selection.

EQUIPMENT AVAILABLE

Most large thermal spray shops have access to the spraying equipment required for the processes discussed. There are times although, when new equipment must be evaluated. TABLE 4.1 is a comparison guide for the most routinely used processes in the marine repair industry.

TABLE 4.1

THERMAL SPRAY PROCESS	PLASMA POWDER	ARC WIRE	FLAME POWDER	FLAME WIRE	HVOF
QUALITY	EXCELLENT	EXCELLENT	GOOD	GOOD	EXCELLENT
SPRAY RATE	GOOD	EXCELLENT	MEDIUM	MEDIUM	GOOD
PORTABILITY	POOR	EXCELLENT	EXCELLENT	GOOD	EXCELLENT
EQUIPMENT MAINTENANCE	MEDIUM	LOW	LOW	MEDIUM	HIGH
OPERATOR SKILL REQUIRED	HIGH	LOW	LOW	MEDIUM	MEDIUM
COST	HIGH	LOW	LOW	LOW	HIGH

This table demonstrates that many variables must be taken into account when selecting the best thermal spray process for a given application. In practice it takes experience to identify and accurately weigh all of the variables involved. The following is a description of these common thermal spraying processes and a summary of their advantages and limitations.

PLASMA POWDER

With the plasma powder process, an arc that is created between a tungsten electrode and a copper nozzle produces the heating zone. The tungsten electrode and nozzle are located in a conducting channel inside the plasma powder gun. A gas or gas mixture passes through this channel. The arc in the gas channel excites the gas into a plasma state, creating temperatures higher than can be obtained with any type of oxygen fuel mixture. The gas or gas mixture then exits the gun forcing the plasma flame outside the gun. A powder is fed into the flame where it is melted and propelled at sonic or higher velocities to the substrate.

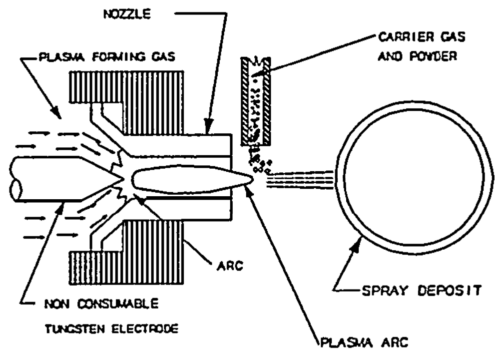


Figure 4.1

ADVANTAGES

Reliable

Capable of spraying all thermal spray powders, including ceramics

Produces coatings with high bond strengths, low porosity, and low oxides

Easily adapted to robotics

Low substrate heat input

Good deposition rates

LIMITATIONS

Not as portable as some of the other thermal spray processes

High operating cost

High start-up cost

Requires highly skilled thermal spray operators

High intensity ultra-violet light can quickly cause flash bums to inadequately protected skin or eyes

May require water cooling

High noise levels generally require double hearing protection for operators and any other personnel who must work nearby

ARC WIRE

The heating zone with the arc wire process forms when an electric arc passes between two continuously fed metallic wires. Compressed air or an inert gas then atomizes and propels the molten material to the substrate.

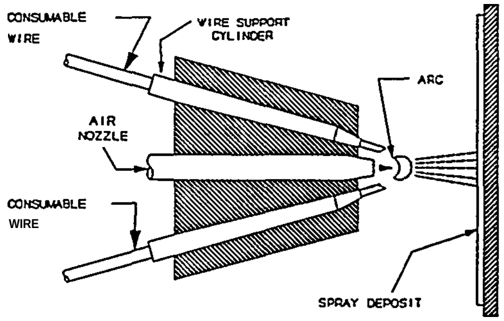


Figure 4.2

ADVANTAGES	LIMITATIONS
Very portable	Can not thermal spray ceramics (except for a few specialty cermet wires designed for producing non-skid coatings)
Easy to operate	Higher porosity and oxides than plasma powder and high velocity oxygen fuel coatings
High deposition rates	High intensity ultra-violet light can quickly cause flash bums to inadequately protected skin or eyes
Relatively inexpensive to purchase and operate	
Produces coatings with high bond strengths	
Has the ability to use low cost materials such has welding wires	
Very low heat input	

FLAME WIRE

The flame wire process uses an oxygen fuel flame to create the heating zone. A wire continuously fed into the heating zone is melted, atomized, and then propelled onto the substrate by the force of the burning gasses and compressed air.

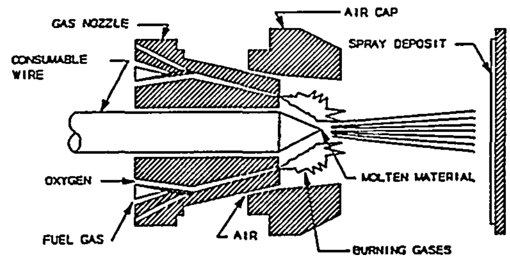


Figure 4.3

ADVANTAGES

Medium deposition rates

Capable of spraying most thermal Spiny wires

Relatively inexpensive to purchase and operate

Very portable

Easy to operate

LIMITATIONS

Medium ratio of heat conveyed into the substrate

Unable to spray ceramic materials without some special equipment

Low velocity spiny stream

Lower bond strengths than arc wire, plasma powder, and high velocity oxygen fuel

FLAME POWDER

The flame powder process uses an oxygen fuel flame to create the heating zone. Powder enters the heating zone and melts. The molten material is then propelled to the substrate by the force of the burning gasses and compressed air

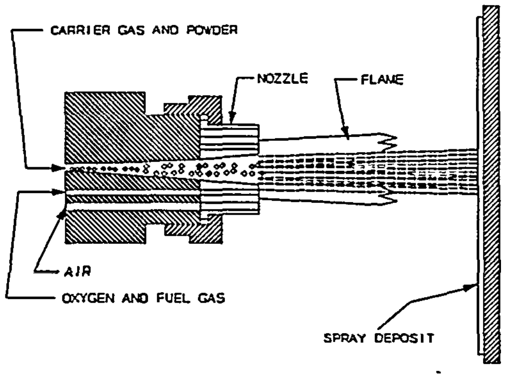


Figure 4.4

ADVANTAGES	LIMITATIONS
Relatively high deposition rates	High ratio of heat conveyed into the substrate
Capable of spraying most thermal spray powders	Unable to spray some ceramic materials
Low noise levels	Low velocity spray stream
Relatively inexpensive	
Very portable	
Easy to operate	

HIGH VELOCITY OXYGEN FUEL

The HVOF process is one of the most recently developed of the thermal spray processes. This process uses the combustion of oxygen and fuel (typically propane, propylene, or hydrogen) mixtures at high pressures. This mixture of oxygen and fuel gas bums and is accelerated to supersonic speeds. Thermal spray powder is injected into this constricted flame. The powder then accelerates in the high velocity flame (4500 - 7000 feet per second) When the thermal spray material collides with the substrate it plasticizes, flattens and adheres to form a coating.

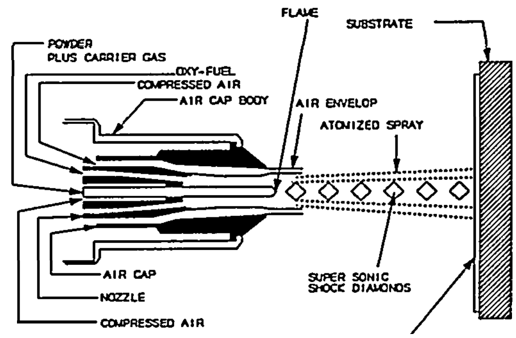
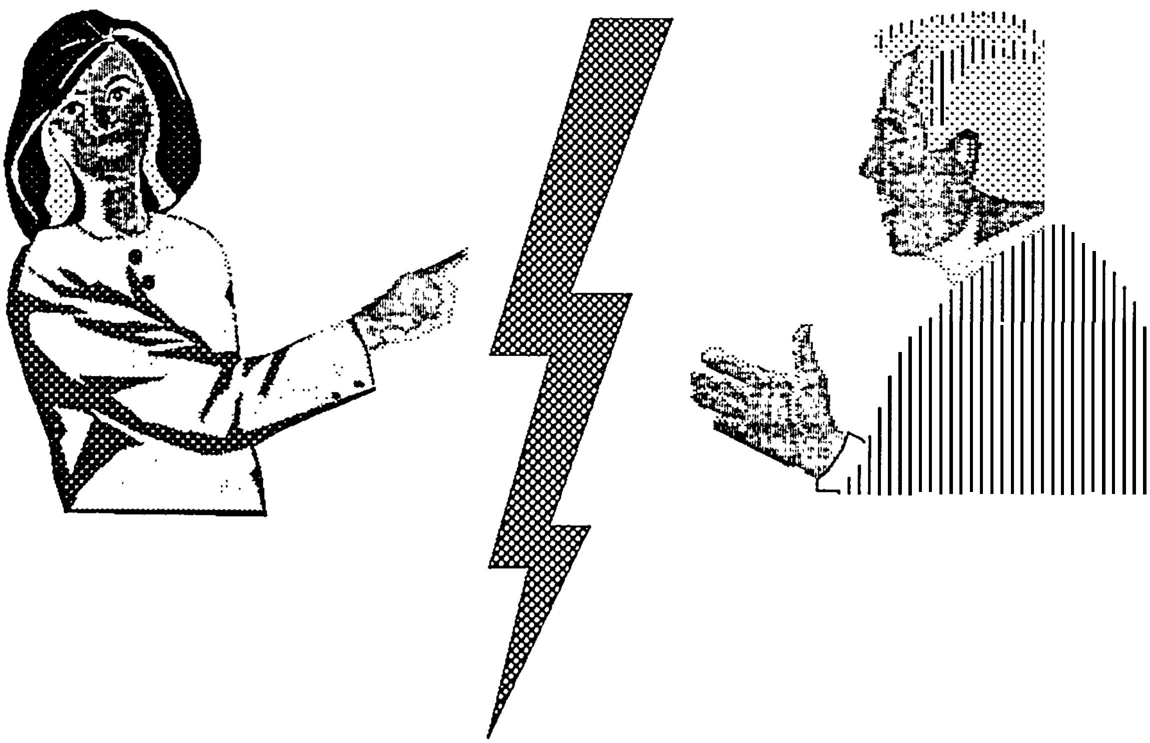


Figure 4.5

ADVANTAGES	LIMITATIONS
Low thermal energy	High noise levels generally require double hearing protection for operators and any other personnel who must work nearby
High kinetic energy	Relative expensive
Coatings with low porosity, low oxide content, low residual stress, and exceptionally high bond strengths	Requires highly skilled operators
Reduced changes in the phase composition of the thermal spray material	

SECTION 5

COATING SELECTION



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5 COATING SELECTION

COATING SYSTEMS

Many factors must be considered when selecting a coating system that will be used on ship machinery components. Factors that are considered when making coating selections for maritime machinery components include, but not limited to are, base material, type of area to be repaired, operational environment, thermal spray material available, finishing capabilities, and thermal spray process to be used.

COATING SYSTEM SELECTION

Each organization assigns the responsibility of thermal spray coating system and process selection to different groups or different levels of management. If the application is one that has been accomplished by the thermal spray facility many times, such as steam valve stems, the selection may be left to the operator performing the work. If the application is a new one, but still similar to other applications accomplished by the thermal spray facility, then the coating system selection may be made by a review group consisting of production shop, thermal spray engineering, and design engineering personnel.

Making a coating selection for a ***new*** thermal spray application that is not similar to anything before, is a difilcult task. Because of the criticality of some ship's machinery components, it is advised that laboratory and land based equipment in-service testing be conducted for new thermal spray applications.

COATING SELECTION CHARTS

The following charts were created by the Naval Surface Warfare Center (Annapolis) and Puget Sound Naval Shipyard. A broad review by these facilities of available thermal spray materials, technical literature, and those Naval Facilities experience in the thermal spray field has led to the development of the subsequent coating selections charts that can be used for most maritime machinery component applications.

TABLE 5.1 POWDER COATINGS FOR CARBON, LOW ALLOY, STAINLESS STEEL, AND CAST IRON
TABLE 5.2 POWDER COATINGS FOR NICKEL BASE ALLOYS
TABLE 5.3 POWDER COATINGS FOR COPPER BASE ALLOYS
TABLE 5.4 WIRE COATINGS FOR CARBON, LOW ALLOY, STAINLESS STEEL, NICKEL BASE ALLOYS, AND COPPER BASE ALLOYS
TABLE 5.5 THERMAL SPRAY POWDER MANUFACTURERS

Any facilities desiring information or assistance making coating selections, can contact the authors of this manual at Puget Sound Naval Shipyard.

TABLE 5.1
CARBON, LOW ALLOY, STAINLESS STEEL, AND CAST IRON

COATING SYSTEM	STEAM		FRESH/SALT WATER		AIR/OIL	
	FIT	* SEAL	FIT	* SEAL	FIT	* SEAL
PP-25	N	N	N	N	N	N
444	3	N	3	N	1	N
445	N	N	N	N	N	N
447	4	N	4	N	2	N
21021	2	N	2	N	4	N
21031	1	N	1	N	3	N
PP-25/130	N	N	N	N	N	N
444/130	N	N	N	3	N	1
445/130	N	N	N	N	N	N
447/130	N	N	N	4	N	3
21021/130	N	N	N	2	N	4
21031/130	N	N	N	1	N	2
PP-25/143	N	N	N	N	N	N
444/143	N	3	N	7	N	5
445/143	N	N	N	N	N	N
447/143	N	4	N	8	N	7
21021/143	N	2	N	6	N	8
21031/143	N	1	N	5	N	6

1-8 = NUMBER LISTED IN COLUMN - RANKING BASED ON MIL-STD-1687 OR PSNS QUALIFIED PROCEDURE AND EXPERIENCE - THE NUMBER 1 INDICATES THE BEST COATING SYSTEM SELECTION FOR THE LISTED APPLICATION. THE COATING SYSTEM WITH THE LARGEST NUMBER IN THE COLUMNS COULD BE USED, BUT WOULD BE THE LAST RECOMMENDED SYSTEM FOR THE APPLICATION.

= POOR SELECTION BASED ON EXPERIENCE OR NOT PERMITTED

(*) = DOES NOT INCLUDE LABYRINTH SEALS

NOTE: WHEN EVER POSSIBLE GRINDING IS THE PREFERRED FINISHING METHOD FOR ALL THERMAL SPRAYED COATINGS.

TABLE 5.2
NICKEL BASE ALLOYS

COATING SYSTEM	STEAM		FRESH/SALT WATER		AIR/OIL	
	FIT	* SEAL	FIT	* SEAL	FIT	* SEAL
PP-25	N	N	1	N	1	N
444	N	N	N	N	N	N
445	N	N	N	N	N	N
447	N	N	3	N	2	N
21021	N	N	2	N	3	N
21031	N	N	N	N	N	N
PP-25/130	N	N	N	1	N	1
444/130	N	N	N	N	N	N
445/130	N	N	N	N	N	N
447/130	N	N	N	3	N	2
21021/130	N	N	N	2	N	3
21031/130	N	N	N	N	N	N
PP-25/143	N	N	N	4	N	4
444/143	N	N	N	N	N	N
445/143	N	N	N	N	N	N
447/143	N	N	N	6	N	5
21021/143	N	N	N	5	N	6
21031/143	N	N	N	N	N	N

1-8 = NUMBER LISTED IN COLUMN - RANKING BASED ON MIL-STD-1687 OR PSNS QUALIFIED PROCEDURE AND EXPERIENCE - THE NUMBER 1 INDICATES THE BEST COATING SYSTEM SELECTION FOR THE LISTED APPLICATION. THE COATING SYSTEM WITH THE LARGEST NUMBER IN THE COLUMNS COULD BE USED, BUT WOULD BE THE LAST RECOMMENDED SYSTEM FOR THE APPLICATION

= POOR SELECTION BASED ON EXPERIENCE OR NOT PERMITTED

(*) = DOES NOT INCLUDE LABYRINTH SEALS

NOTE: WHEN EVER POSSIBLE GRINDING IS THE PREFERRED FINISHING METHOD FOR ALL THERMAL SPRAYED COATINGS.

TABLE 5.3 COPPER BASE ALLOYS						
COATING SYSTEM	STEAM		FRESH/SALT WATER		AIR/OIL	
	FIT	* SEAL	FIT	* SEAL	FIT	* SEAL
PP-25	N	N	N	N	N	N
444	N	N	N	N	N	N
445	N	N	1	N	1	N
447	N	N	N	N	N	N
21021	N	N	N	N	N	N
21031	N	N	N	N	N	N
PP-25/130	N	N	N	N	N	N
444/130	N	N	N	N	N	N
445/130	N	N	N	1	N	1
47/130	N	N	N	N	N	N
21021/130	N	N	N	N	N	N
21031/130	N	N	N	N	N	N
PP-25/143	N	N	N	N	N	N
444/143	N	N	N	N	N	N
445/143	N	N	N	2	N	2
447/143	N	N	N	N	N	N
21021/143	N	N	N	N	N	N
21031/143	N	N	N	N	N	N

1-8 = NUMBER LISTED IN COLUMN - RANKING BASED ON MIL-STD-1687 OR PSNS QUALIFIED PROCEDURE AND EXPERIENCE - THE NUMBER 1 INDICATES THE BEST COATING SYSTEM SELECTION FOR THE LISTED APPLICATION. THE COATING SYSTEM WITH THE LARGEST NUMBER IN THE COLUMNS COULD BE USED, BUT WOULD BE THE LAST RECOMMENDED SYSTEM FOR THE APPLICATION

= POOR SELECTION BASED ON EXPERIENCE OR NOT PERMITTED

(*) = DOES NOT INCLUDE LABYRINTH SEALS

NOTE: WHEN EVER POSSIBLE GRINDING 1S THE PREFERRED FINISHING METHOD FOR ALL THERMAL SPRAYED COATINGS.

TABLE 5.4
WIRE COATINGS FOR CARBON, LOW ALLOY, STAINLESS STEEL, NICKEL BASE ALLOYS, AND COPPER BASE ALLOYS

ARC-WIRE FLAME-WIRE COATING SYSTEM	WEAR RESISTANT	CORROSION RESISTANT	SINGLE POINT TOOLING RECOMMEND	SUBSTRATE MATERIALS
410	Yes	No	No	CARBON, LOW ALLOY, STAINLESS STEEL
309	Yes	No	No	CARBON, LOW ALLOY, STAINLESS STEEL
METCOLOY #2	Yes	No	No	CARBON, LOW ALLOY, STAINLESS STEEL
70S-4	Yes	No	No	CARBON, LOW ALLOY STEEL
EN-60	No	No	Yes	NICKEL BASE ALLOYS
C-22	Yes	Yes	No	STAINLESS STEEL & NICKEL BASE ALLOYS
625	Yes	Yes	No	STAINLESS STEEL & NICKEL BASE ALLOYS
HAYNES-75-B	Yes	No	Yes	CARBON, LOW ALLOY STEEL
AMPCO-10	No	Yes	Yes	COPPER BASE ALLOYS

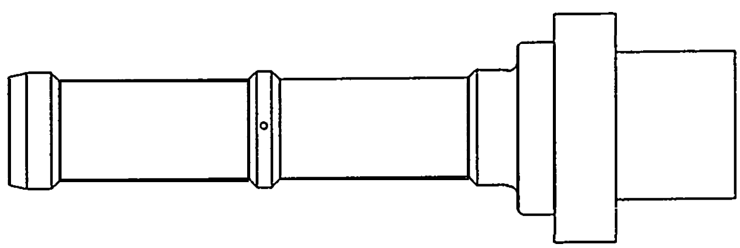
TABLE 5.5
THERMAL SPRAY POWDER MANUFACTURERS

DRESSER	PP-25
SULZER/METCO	130, 143, 444,445, 447
EUTECTIC	21021,21031

The thermal spray materials tabulated in this manual have been so listed because of the experience Naval facilities have had using these manufacturers in the past. It is to be noted that the authors of this manual are aware that other companies also produce excellent quality and equivalent thermal spray materials.

SECTION 6

PREPARING A MACHINERY COMPONENT FOR THERMAL SPRAYING



PREPARED BY: PUGET SOUND NAVAL SHIPYARD

6 PREPARING A MACHINERY COMPONENT FOR THERMAL SPRAYING

INTRODUCTION

Preparation of machinery components for thermal spray repair involves four operations. Cleaning, the frost operation, is repeated before each subsequent operation; once (prior to undercutting) to remove years of accumulated grime, once prior to masking to remove machining oils and to remove subsurface contaminants exposed during undercutting, and the third cleaning is performed just prior to anchor tooth blasting to assure that no trace oils are on the ready-to-spray surface. The next operation is undercutting, which is performed according to design criteria discussed in this section. Masking, the third operation, is done to protect sensitive parts of the component from grit blast damage and to insure that spray material covers no more than the intended areas. The last operation of preparation is anchor tooth blasting, which is usually delayed for time considerations until the spraying and associated equipment is staged and test fired.

CLEANING METHODS

Cleanliness of the area to be thermal sprayed has a direct influence on how well the coating adheres to the substrate material. All oil, grease, rust, scale, paint, or any other substance that would inhibit the thermal spray coating from adhering to the substrate must be removed prior to final surface preparation. The machinery component should be cleaned, both before and after undercutting. Also, it must be cleaned again just before final surface preparation. The methods currently used to clean machinery components in the maritime industry include baking, solvent washing, vapor decreasing, mechanical cleaning, and abrasive blasting.

1. Solvent washing is the most commonly used method for cleaning maritime machinery components that are to be thermal sprayed.
2. Vapor decreasing is used by some facilities as their main method to remove contaminants from components that are to be thermal sprayed.

< WARNING AND PRECAUTIONS>

Due to the flammable and toxic nature of most solvents. proper precautions must be followed during solvent cleaning. Precautions shall also be taken to protect any parts which may be attacked by the solvents. Do not clean previously thermal sprayed parts with acids or other corrosive fluids, as deterioration of the existing coating may result. If corrosive cleaners must be used, pre-existing thermal sprayed surfaces shall be completely protected or resprayed. Follow safety precautions listed on material labels and/or material safety data sheets.

3. Heat cleaning may be used on porous materials that have been contaminated with grease or oil. It is best to solvent clean before heat cleaning starts. Castings should be baked for four hours to char and/or drive out the foreign material from the pores. Steel castings should be heated at 650° F maximum. Aluminum castings should be heated to no more than 300° F; age hardened alloys must be kept below the aging temperature.

If there is any possibility that heat cleaning may change the existing heat treatment on the component or that distortion may occur, a welding engineering review should be considered before heat cleaning.

4. Abrasive blasting (some times called corrosion removal blasting) may be used to remove heavy or insoluble deposits. Inexpensive, non-reusable blasting grit is recommended for this purpose. Another good source of grit is partially broken down aluminum oxide which has been recycled from anchor-tooth blasting operations. For delicate surfaces, non-abrasive blast media may work better.
5. Replacements for chlorinated solvents have been developed by a number of companies. These solvents are designed to be significantly less hazardous to personnel and to the environment than the chlorinated solvents.
6. Solvent cleaning just prior to masking is important in order to permit tape or masking compounds to adhere as well as possible to areas which must be protected from blast and spray streams.

UNDERCUTTING

Undercutting on maritime machinery components that are to be thermal sprayed is accomplished to remove existing coatings, to remove damaged or contaminated base material, and to allow for a uniform finished coating thickness. Because most machinery components thermal sprayed at marine repair facilities are cylindrical in shape, a lathe is normally used for undercutting. To help insure uniform coating thickness, undercutting and finishing processes should be performed on the same centers. The undercut design is usually completed by the thermal spray operator or thermal spray planner when filling out Section II of the Thermal Spray Job Control Record (See Enclosure 2.2 in Section 2) (Normally, engineers and machinists have not been ttained in undercut design requirements). A typical undercut design is shown in Figure 6.1.

1. UNDERCUT DIAMETER A 3.450””
2. FINISH DIAMETER B 3.5 DO”
3. UNDERCUT AND FINISH ON THE SAME CENTERS

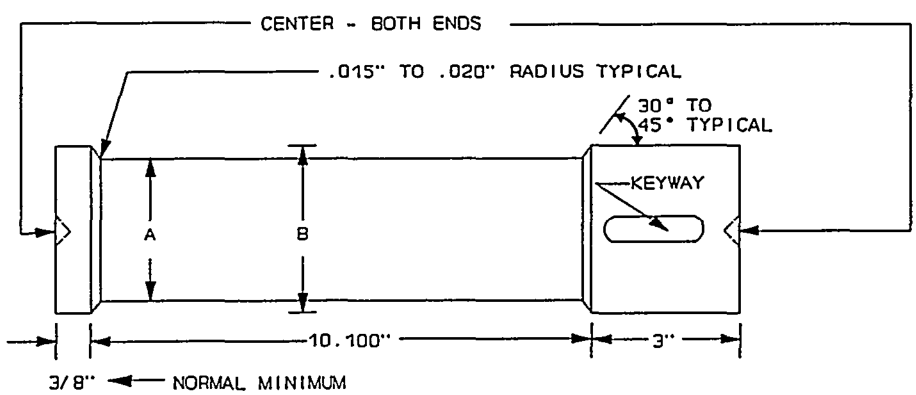


Figure 6.1 TYPICAL UNDERCUT DESIGN

NORMAL UNDERCUT GUIDELINES (FOR SHAFTS AND OUTSIDE DIAMETERS)

1. A radius of 0.015” to 0.020” should be cut at the comers of the undercut.

2. The shoulders should typically be no closer than 3/8” from an unprotected outside corner. (See page 6.7 for special conditions, and for exceptions to this general guideline.)
3. At each end of the undercut section on the machinery component, shoulders shall be cut at an angle of 30 to 45 degrees measured from the axis of the component (See Figure 6.2).

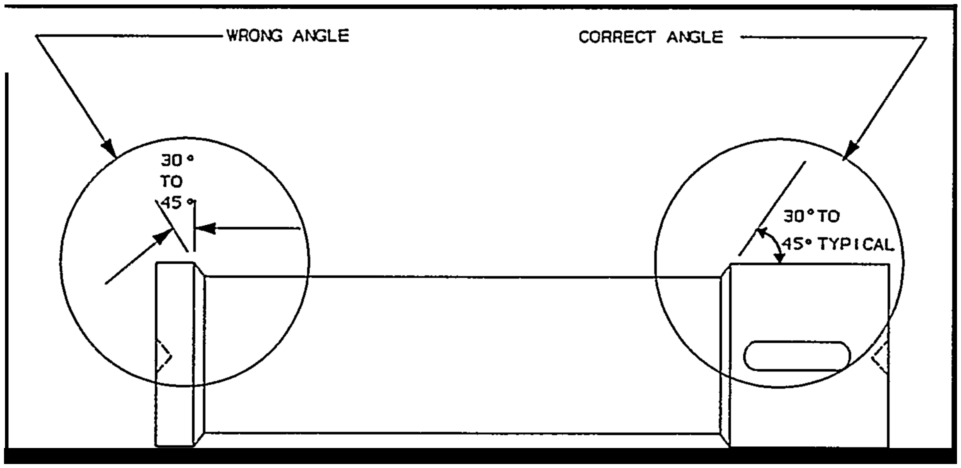


Figure 6.2 ANGLE OF SHOULDER

4. The depth of the undercut determines the thickness of the finished machined thermal sprayed coating. The optimum thickness of the sprayed coating is determined by the type of component, by the coating function, and by application area duty and the contraction rate of the chosen material(s). The component type and service conditions are the major factors in determining deposit thickness. These conditions can be reduced to the following recommendations:

- ☐ Recommended maximum depth of undercut for shafts is given in TABLE 6.1 in this section.
- ☐ If TABLE 6.1 permits more than .020” depth of undercut, a coating thickness limitation may apply. Check manufacturer’s recommendation or TABLE 6.2 (Excerpted from MIL-STD-1687, TABLE 1) for normal coating thickness limits.
- ☐ If the sprayed deposit is not a wearing surface, no minimum thickness need be specified other than that the deposit should be of uniform thickness and meet the minimum thickness requirements of the applicable spray procedure.
- ☐ If the deposit is a wear surface, the minimum deposit thickness is determined by the maximum amount of wear the surface is allowed in service, plus .005” for each coating material to maintain adequate bonding and to distribute localized load forces. (Example, a valve stem: 0.005” Bond Coat, 0.005” Ceramic, plus 0.005” Ceramic Wear Allowance - Total, 0.015” minimum depth of undercut).

NOTE: If wear or undercut depth reduces the strength of the component enough to make it unusable for service, then thermal spray must be rejected as a repair option (See TABLE 6.1).

CONDITIONS TO AVOID

1. Dovetails or even angles steeper than 45° significantly reduce coating quality in these areas, and (in the case of dovetails) may even leave voids in areas shadowed from direct particle impact. These defects are likely to cause premature coating failure, and they may be exposed during finish machining operations. Figures 6.3 and 6.4 are examples of poorly designed undercuts.
2. Although keyways must sometimes be included within the spray area, they should be avoided, if possible, because of the stress on the keyway edge.
3. Taper and run out (eccentricity) must be strictly limited in the undercut area in order to minimize loss of shaft strength and to maintain even coating thickness. This is especially important when spraying coatings such as ceramics which have severely limited buildup tolerance.
   a. Maximum taper is typically 0.002".
   b. Maximum runout is typically 0.001".

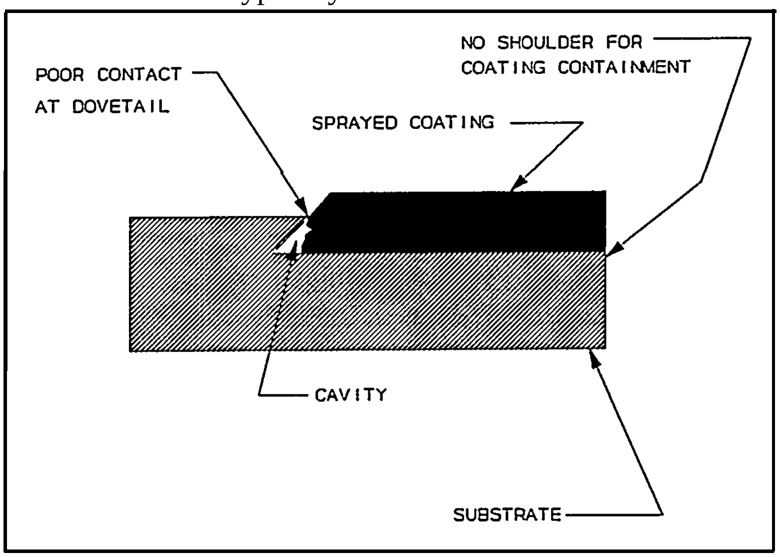


Figure 6.3 POORLY DESIGNED UNDERCUT

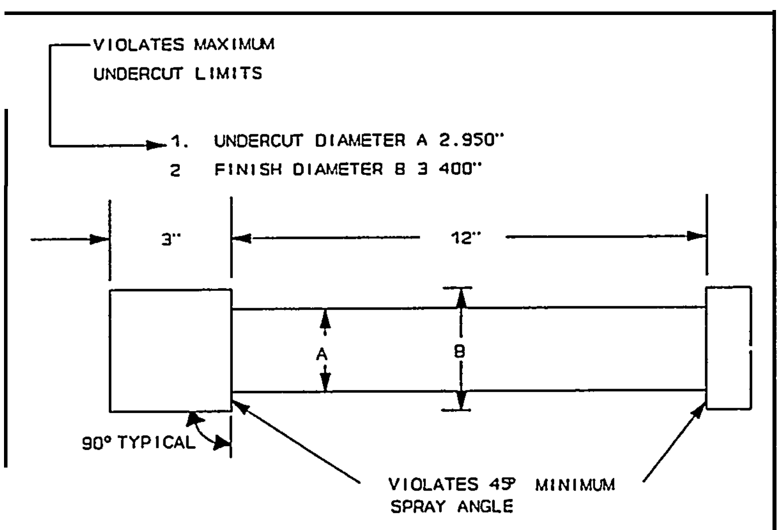


Figure 6.4 POORLY DESIGNED UNDERCUT

TABLE 6.1		
RECOMMENDED MAXIMUM DEPTHS OF UNDERCUTTING		
DIAMETER OF SHAFT	CLASS A SERVICE	CLASS B SERVICE
UNDER 1“	2.5% OF DIA.	4% OF DIA.
111-211	0.025”	0.040”
2" - 4"	0.035”	0.050”
4" - 6"	0.045”	0.060”
OVER 6“	0.055”	0.070”

CLASS A SERVICE For shafts or journals operating under a heavy bearing load or subject to severe service and high pressurre; applications where the maximum safety is required.
CLASS B SERVICE For normal duty lubricated bearing service; applications where a minimal safety factor is required.

TABLE 6.2

NORMAL CONDITION COATING LIMITS

SPRAY MATERIAL	PROCESS1/	MAXIMUM COATING THICKNESS IN NCHES)2/
CARBON STEEL -WIRE	AW	0.050
AUSTENITIC STAINLESS (WITH BOND COAT) -WIRE	FW	0.050
420 STAINLESS -POWDER -WIRE -WIRE	PP AW FW	0.075 0.050 0.050
NICKEL—ALUMINUM -POWDER	FP, PP	0.050
ALUMINUM-BRONZE -POWDER -WIRE	FP, PP FW	0.125 0.125
NICKEL-COPPER -POWDER -WIRE	FP, PP AW	0.040 0.040
COPPER-NICKEL -POWDER -WIRE	FP, PP AW	0.040 0.040
ALUMINUM-TITANIA -CERAMIC POWDER	FP, PP	0.015
BABBITT -POWDER -WIRE (WITH BOND COAT)	FP, AW	NO LIMIT

(From MIL-STD-1687)

1/ Spray processes are arc-wire (AW), flame-wire (FW), plasma-powder (PP), and flame powder (FP), applied as single or dual coating systems. Dual coating systems are identified by the bond coat material and finish coat material.

2/ The maximum coating thickness that can be successfully applied depends on the specific component dimensions, the specific chemistry of the spray material, and other factors.

UNDERCUT DESIGN FOR SPECIAL CONDITIONS

1. Occasionally, damage to a shaft may extend past the normal length of the undercut limits. If so, one or more of the following guidelines will apply:
   a. Special masking procedures may permit the undercut to extend to 1/8” from smfaces which must be protected from grit blast damage or 1/16” from end of shaft.
   b. If damage extends to the end of the shaft, and if no mechanical or metallurgical damage will be caused by welding, a weld bead may be deposited around the end of the repair area to provide the 1/16” minimum shoulder needed for thermal spraying.
   c. If valve stem backseat design permits minor reduction in its length during finish grinding, then the undercut may extend to the edge of the backseat (See Figure 6.5).

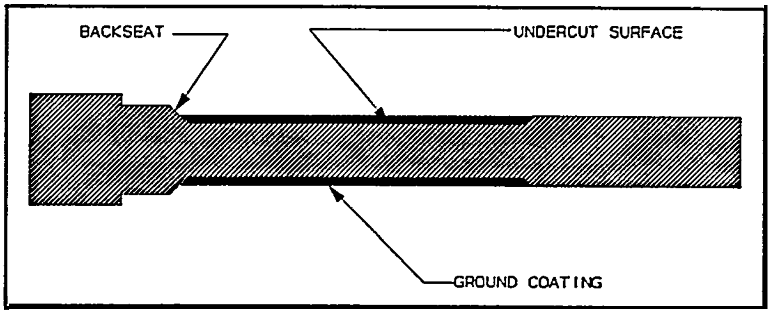


Figure 6.5 SPECIAL UNDERCUT DESIGN ON A VALVE STEM

   d. When weld buildup cannot be performed around the end of a shaft, a chamfer step may be cut at the end of the shaft (See Figure 6.6).

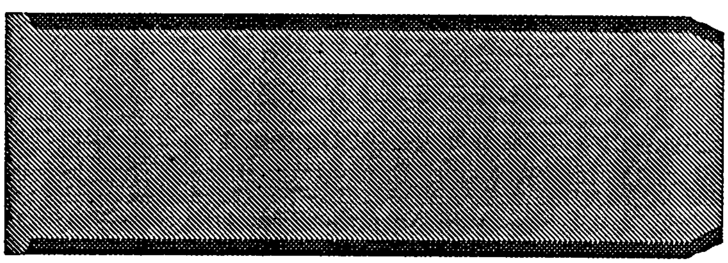


Figure ***6.6*** **UNDERCUT DESIGN WITH CHAMFER**

2. Depth of undercut limits for TABLE 6.1 may be exceeded only under the following conditions.
   a. Limits of TABLE 6.1 may only be exceeded if conditions of both b. and c. (below) are met.
   b. Undercut does not exceed either limits of thermal spray material manufacturers recommendations or limits of service/mock-up testing experience.
   c. Engineers determine that undercut does not affect service requirements, such as shaft strength due to the geometry of the component (See Figure 6.7).
   d. The limits of TABLE 6.2 tend to be conservative due to factors listed in Note 2 of that table. If surface damage is deeper than the limits of TABLE 6.2, consult thermal spray material manufacturers for guidance.

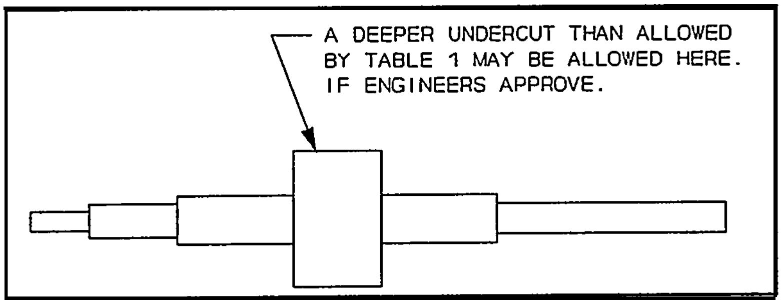


Figure 6.7 ABNORMAL UNDERCUT DESIGN

3. From time to time, shafts will be received in an undersize condition. These may sometimes be sprayed without undercut if remaining spray material after finish machining is at least as thick as the minimum requirements of the procedure and application (See normal guidelines for depth of undercut, TABLES 6.1 AND 6.2). If possible, a coating thickness of .010” per side should be applied. A minimum thermal sprayed coating of .005” per side is recommended for machinery components. If the coating is applied to thin, the thermal sprayed coating may overheat and cause spalling from the substrate.
4. A hole in the middle of a spray area may be treated in one of three ways..
   Interrupt the spray zone (See Figure 6.8).
   a Treat the hole in a manner similar to the spraying of keyways by using inserts.
   c. If the function of the hole is not affected by the spray process, the hole could be ignored.
5. Extremely heavy buildup (in excess of. 125”) should not be attempted without years of experience. and practical experience on mock-ups and throw-away shafts.

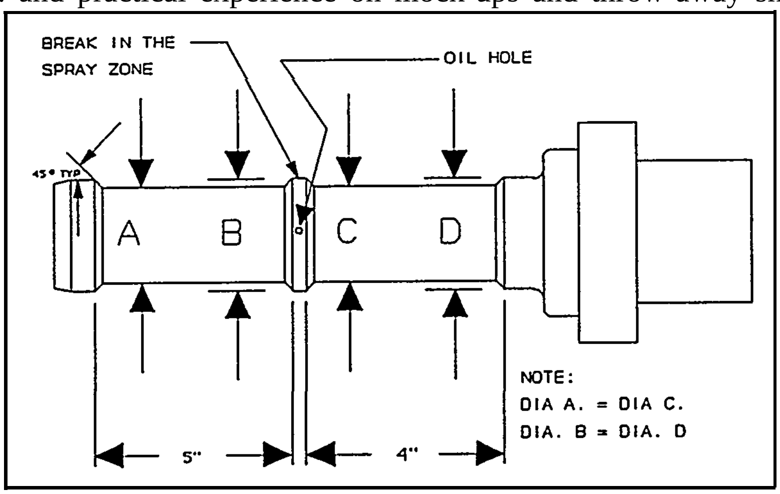


Figure 6.8 UNDERCUT DESIGN FOR OIL HOLE (Interrupted Spray Zone)

INTERNAL **DIAMETERS:**

Basically, the same recommendations apply (both to internal and external diameters), except that maximum thickness must be reduced for inside diameters due to the contraction of the sprayed material. This contraction process tends to shrink the coating away from the substrate, placing high tensile stresses on the bond interface (See Figure 6.9). For some internal diameters, special anchor-tooth blasting, thermal spray, and finishing equipment will be required. Many blasting, thermal spray, and machine equipment manufacturers market such equipment.

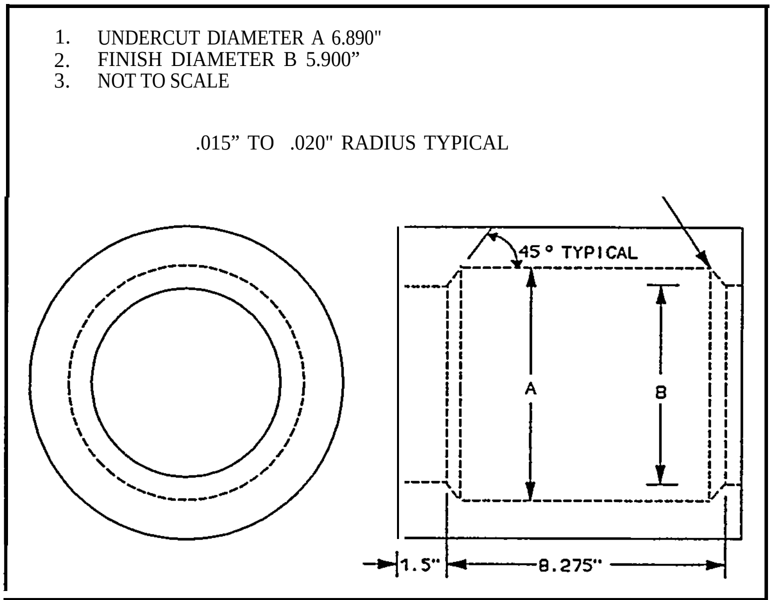


Figure 6.9 EXAMPLE OF AN INSIDE DIAMETER UNDERCUT DESIGN

MASKING

Critical machined areas which are not to be coated and would otherwise be damaged by grit blasting or thermal spraying must be masked. The thermal spray industry uses numerous masking methods and materials in the protection of these critical areas. Masking methods include covering, coating, and shadowing. Masking materials that may be used include tape, pipe, sheetmetal, masking compound, dummy keys, rubber, carbon, etc.

NOTE: Materials which cause corrosion or contamination of the thermal sprayed coating or substrate must not be used.

Almost without exception thermal spray masking must provide two types as well as two levels of protection. For most components, the masking within 4" to 6" of the area to be sprayed provides both blast and spray protection. This means that the masking must withstand the destructive forces of the blast stream as well as the direct heat of the spray stream. Masking which extends beyond this zone may receive some relatively minor heat stress, and it will receive some amount of impact from ricocheting blast media. When applying masking, operators must constantly consider the level, the type, and the direction of stress the masking material will receive. This consideration will help to determine the type and the amount of masking material applied. It will also help to determine the design of re-usable masking fixtures and materials.

TAPES

Several kinds of heat-resistant tape can be used as masking for grit blasting and can be left in place for thermal spraying. These tapes are easy to use and can offer good protection in most machinery component thermal spray applications. After grit blasting, the tape should be inspected to insure its condition is still adequate for use as thermal spray masking.

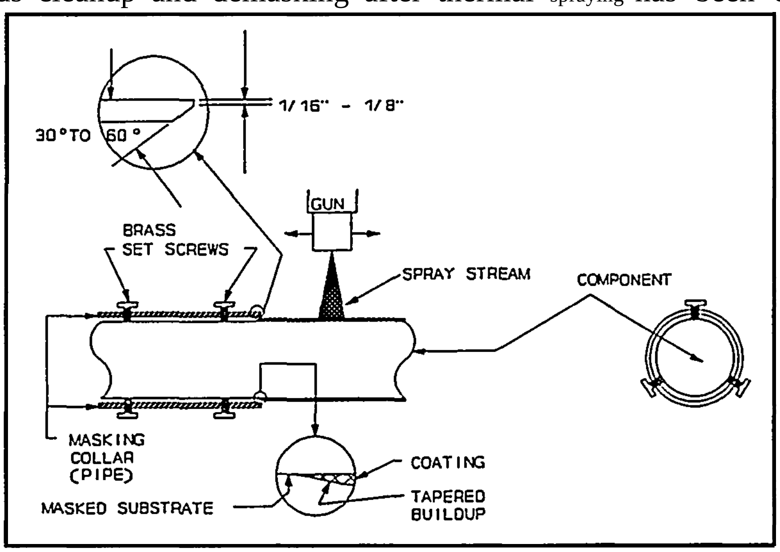
If non heat-resistant tape is used to mask for grit blasting, it must be removed and a heat resistant masking suitable for thermal spraying must be utilized. When applying the tape, it is advisable to use at least two layers, even if a shadow mask is used over it. If tape is the only masking used, three or more layers in the first four inches next to the spray zone may be necessary for adequate protection. After applying each layer, the air bubbles should be removed by firmly rubbing the tape. Inspection of the tape should take place from time to time during blasting and thermal spraying. Tape should be replaced if its ability to protect the critical areas of the machinery component is diminished. Large surfaces may be covered by sheets of light material (cloth, rubber, plastic, etc.) to save tape. The type of material depends on the proximity to spray and blast areas.

MASKING COMPOUNDS

Liquid masking compounds may be used to protect critical areas during the thermal spraying process. These compounds may not be reliable for masking during grit blasting. The compounds may be applied by brushing, spraying, or dipping. When applying the compound, caution should be used to insure it does not get on the area to be thermal sprayed. Many of these compounds are water soluble for easy removal after spraying.

SHADOW MASKING

Because it is usually desirable that the coating edge not end sharply, a technique called shadow masking is frequently used (See Figure (6.10). With this masking method, the area to be protected is partially shielded by raising the mask a little distance (usually, approximately 1/8") away from the component's surface. This causes some of the buildup to taper from the edge of the spray zone to a short distance under the shadow mask. Masking collars must be large enough so that any the anchor-tooth blasting grit can fall out before thermal spraying begins. Otherwise, during spraying grit might become wedged between the collar and the component, causing removal problems during the de-masking operation, and possibly even scarring the component's surface. Because of the nature of the blast and spray environments, shadow masks should be placed over a double layer of tape or masking compound. This helps to prevent blast damage and speeds cleanup and demasking after thermal spraying has been completed.



INSERTS

Some components include recessed areas, such as slots, holes, or keyways. These recessed areas cannot be effectively protected by tape or shadow masks. For these areas, inserts must be made (See Figure 6.11 for keyway insert design.). Materials for inserts vary according to the circumstances, and may include steel, aluminum, brass, copper, rubber, or carbon. Most metals are good for blasting protection and can be re-used many times for this purpose. These metal inserts are usually difficult to remove if left in for spraying. Rubber is only useful for blasting protection. Carbon can only be used during the spray operation. The best procedure for most applications is to make a carbon insert to snugly fit the area and then set it aside in a clean safe place. After this, make a metal insert and firmly seat it in recessed area of the component. After the anchor tooth blasting has been completed, remove the metal insert and replace it with the previously made carbon insert.

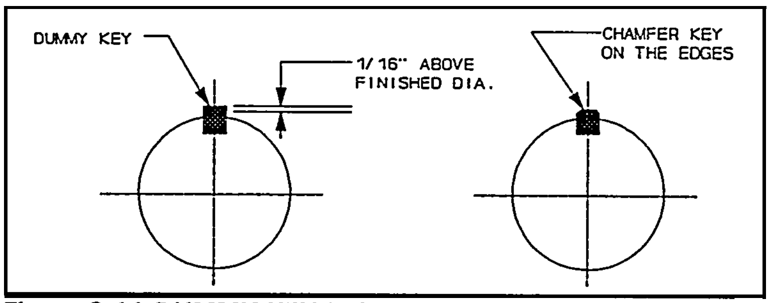


Figure 6.11 DUMMY KEY INSERT

Due to the widely varying nature of the recessed areas, specific instructions cannot be provided for all situations. However, the following guidelines, hints, and "Tricks-Of-The-Trade" will help operators to solve the unusual problems.

1. Inserts for spray protection should protrude no more than 1/16" above the finished surface of the component. This minimizes the shadowing effects of the insert on the coating in the adjacent area. Chamfering the upper edges of the insert will reduce the shadowing effect even more (See Figure 6.11).

NOTE Even when chamfered, the keyway mask partially shadows the edge of the keyway due to the rotation of the shaft.

2. Inserts for blast protection are restricted by two factors; they must survive the blast operation, and they must not prevent a good blast job in the adjacent area.
3. Carbon is usually by far the best material for spray protection because it is easily chipped out of the component after final machining without damage to the adjacent coating. However, it will not survive grit blasting. An insert of a different material must be made for that operation.
4. Inserts must fit snugly in order to prevent the blast or spray stream from blowing them out during initial passes.

NOTE: Inserts rarely fall out after the first pass. Blast or spray media tend to either seat them better or else knock them loose.

5. Steel keystock, if readily available, usually is best for blasting protection of slots and keyways. It generally fits snugly and requires minimal handwork.
6. For odd shaped or sized areas, soft metal is usually the best choice. Soft metal helps prevent scoring on the component. Aluminum is usually readily available, and is very easy to work with. It is easy to hammer, saw, or file. It survives blasting well enough to be re-used a number of times. Aluminum has a high enough melting point to withstand most spray temperatures if it must be left in place for spraying.
7. Machined grooves around the circumference may be masked by tying several wraps of heavy wire or by forming a rod into a temporary snap ring.
8. Snap ring grooves or slots might be masked by an old throw-away snap ring.
9. Material for masking fixtures can generally be acquired without purchasing new material by utilizing the following types of sources:
   a. Pipe, plate, or sheet metal from scrap bins or excess material racks.
   b. Odd shaped pieces from scrap bins.
   c. Throw-away parts removed during disassembly of the component to be thermal sprayed.
   d. Carbon rod readily available in most welding shops.

STAGING

To minimize the time between the surface preparation and the thermal spraying of the component, the thermal spray equipment, measuring equipment (micrometer, contact pyrometer, etc.), and the turning fixture should be set up before surface preparation is started. All tools that will touch the area to be sprayed after final surface preparation must be cleaned of all oil and grease. At this time the thermal spray equipment should also be set up as described in Section 7 of this manual. If the component is to be preheated, the thermal spiny equipment and turning fixture are set up to the same parameters that will be used to apply the thermal sprayed bond coat. The details of the staging operation are discussed in Section 8 of this manual in the portion prior to “Preheating”.

ANCHOR TOOTH BLASTING

Final surface preparation for thermal spraying machinery components is the most important step of the entire coating procedure. Surface roughness of the area to be thermal sprayed has a direct influence on how well the coating adheres to the substrate material.

After masking is completed (just before anchor tooth blasting begins) the spray area must be solvent cleaned one final time. This step insures removal of any contaminants (including finger prints) which may have inadvertently been introduced during the masking process. Except for unusual conditions, this final cleaning is best done using a clean disposable towel which has been permeated with clean solvent. After all contaminants have been removed, the substrate should be protected from becoming re-contaminated. Depending on the circumstances, this protection can range from careful handling to wrapping with an inner layer of clean dry paper or clean cloth or an outer layer of rubber or plastic.

Anchor-tooth blasting with aluminum oxide grit (16-30 mesh) is the most commonly used method to complete the final surface preparation of machinery components to be thermal sprayed. This surface preparation method creates an anchor tooth pattern for the coating to adhere to (See Figure 6.12). To help insure the use of clean and correctly sized aluminum oxide, many facilities do not recycle grit in this operation. Instead, they move the expended grit to a different blast unit to be recycled for non-anchor tooth operations, such as corrosion removal or cleaning/descaling purposes. Thermal spray facilities typically use a dedicated blasting cabinet to complete anchor tooth blasting. A separate blasting cabinet should be used for cleaning operations. This helps to prevent oil contamination of surfaces which have already been cleaned and are receiving final anchor tooth blasting.

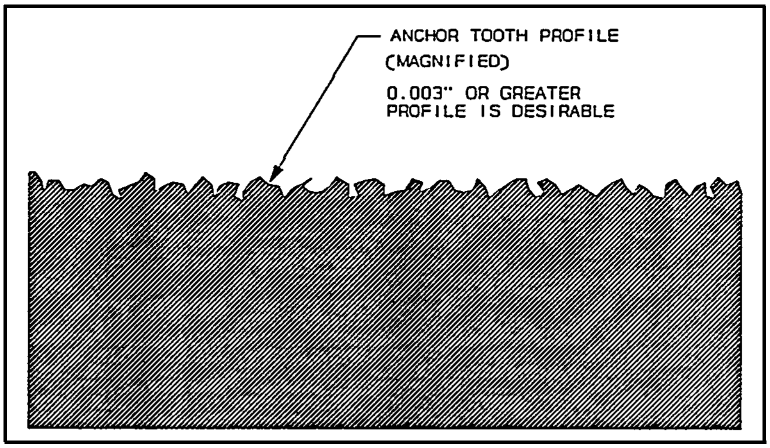


Figure *6.12* ANCHOR TOOTH PROFILE

The following is a list of blasting related equipment recommended for performing all blasting operations associated with the thermal spray operation.

1. Compressed air is limited to a maximum of 5 milligrams of condensed hydrocarbons per cubic meter and a dew point of + 14°F or lower at standard temperature and pressure (68"F, 14.5 lb/in^2 absolute) prior to the final faltering and moisture separation unit. For abrasive blasting, minimum air pressure at the blast generator of 50 lb/in^2 and 75 lb/in^2 is required for pressure type and suction type blasting units, respectively.
2. Air pressure regulators with pressure gauges.
3. Steel blasting table and cabinet.
4. Oil and moisture separator.
5. Blast nozzle equipped with a dead-man switch.
6. Aluminum oxide grit.
7. Profile tape.
8. Dial micrometer.

The Military Standard, "Thermal Spray Processes for Naval Ship Machinery Applications" (MIL-STD-1687), requires a 2 to 4 roils anchor-tooth surface profile for final surface preparation. This Standard also states that when distortion may be encountered due to part configuration, the anchor-tooth pattern may be reduced to a 1 mil profile (minimum) provided that a procedure qualification with the 1 mil profile meets all other MIL-STD-1687 requirements. Lower blasting pressure or greater nozzle-to-substrate distance can also be an effective method for reducing or eliminating distortion.

A good method for measuring the anchor tooth pattern of a component is with the use of profile tape and dial micrometer.

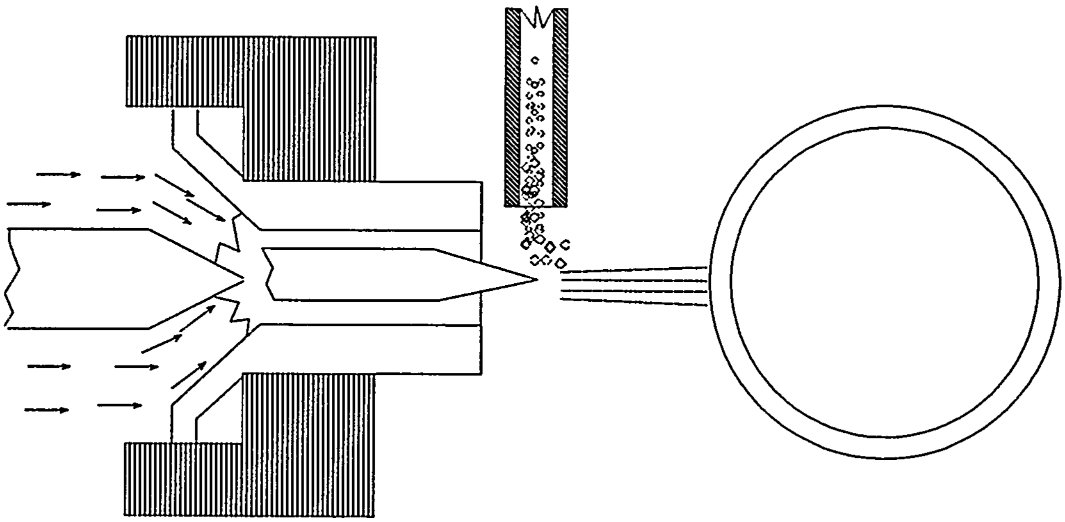
Visual inspection of the anchor-tooth profile shall assure that surface appearance is uniform. Steel substrates shall have a white metal blast finish, defined as a gray-white, uniform metallic color. Oil, grease, scale, paint, or any contaminant shall not be present on the substrate to be thermal sprayed after final surface preparation. After the final surface preparation, the area to be sprayed must not come in contact with any item which would contaminate the surface. Areas to be thermal sprayed should be handled with clean material. Even the oil from fingerprints may cause a coating failure. The slightest presence of oil, oxidation or other foreign material on the surface to be sprayed may result in separation of the thermal spray coating. The blasted surface is rejectable if the white metal blast condition is lost.

CONCLUSION

Producing a quality thermal spray coating requires a high degree of control over all stages of operations in this Section. The steps listed in this Section are critical to the success in creating a high quality thermal spray coating. It is essential during these steps for thermal spray personnel to understand the criticality of the cleanliness requirements.

SECTION 7

THERMAL SPRAY OPERATIONS



PREPARED BY: PUGET SOUND NAVAL SHIPYARD

7 THERMAL SPRAY OPERATIONS

INTRODUCTION

Producing a quality thermal sprayed coating requires a high degree of control over each stage of operation. These stages include application and coating selections, cleaning, undercutting, masking, surface preparation, thermal spraying, and finishing. Application of a quality coating requires trained and skilled mechanics who know exactly what must be accomplished during each of these stages, particularly during the thermal spray operation. This section provides information about setting up and operating thermal spray and related equipment during the actual spray operation. This Section was developed to help trainees, journeyman level mechanics, and other interested personnel improve their skills and gain insight into the day-to-day operation of a thermal spiny facility.

EQUIPMENT SETUP

The frost step of the spray operation is usually performed before anchor tooth blasting begins. Tools must be staged, and rotating equipment must be adjusted. In some cases, components must be temporarily mounted in the futures to assure correct fit, alignment and clearances. Finally, the spray equipment must be started up. There are many equipment manufacturers who sell thermal spray systems. It is beyond the scope of this manual to list the steps for setting up all of the systems available on the market. Set up procedures are provided by the equipment manufacturers in their operating manuals and training programs. Trained and qualified operators must know how to set up and use the spray equipment used at their facilities. Appendix (7.1) is an example of a start up procedure that can be used for one model of a Plasma Spray System. When using other equipment or processes, the equipment manufacturer's recommended start up procedures should be followed.

TOOLS

Thermal spray operators use a variety of tools in the performance of their duties. An assortment of generic and specialized hand tools, such as hammers, screwdrivers, wrenches, and cutting tools accumulates for the various purposes of building, adjusting, and maintaining all of the fixtures, masks, and spray equipment. In addition, four special quality assurance tools are required for controlling and assuring a quality thermal sprayed coating.

1. Compressible plastic film and the related thickness gage are used to measure the anchor tooth height and to give an indication of the anchor-tooth blast quality.
2. Vernier or dial caliper or micrometers are used to measure diameter changes. Highly accurate readings are essential for controlling deposition rates (with ceramics, as refine as O.0005" per pass may be required). This can be a real challenge on rough surfaces which may expand and contract throughout the spray process.
3. Temperature monitoring instruments (usually contact pyrometers) help operators control the temperature of a component.

As operators gain experience, both in general and with specific components, the number of stops for taking temperature readings may be reduced; however, frequent readings are still necessary to keep positive control of component and coating temperatures.

4. A 10X magnifier is used as an aid during visual inspections to analyze coating quality. Specific details of visual inspections are covered in the Quality Assurance section of this manual.

TURNING FIXTURE

Any machinery component should be, if at all possible, sprayed using automatic or semi-automatic equipment with a gun fixture mounting. This is to maintain the close control of parameters so necessary for the types and amounts of coating buildup typical for these applications. Relative movement between the gun and substrate must be accurately controlled. The angle of the thermal spray gun should be as close as possible to 90° to the substrate. The gun angle must never be less than 45° to the substrate. In general, turning fixtures used for thermal spraying can be anything that will hold and rotate the component, have a mount to hold the spray gun, meet the speed and feed requirements of the procedure, and will not contaminate the area to be thermal sprayed. Several manufacturers sell turning fixtures designed specifically for thermal spray operations. Many thermal spray facilities use a lathe for their turning fixture. These lathes are usually equipped with a self centering head chuck and a live, spring loaded center in the tail stock. If possible, the undercutting, spraying, and finishing should be accomplished on the same centers of the component. An ideal fixture is a CNC Machining Center designed to undercut/prep/spray/finish. Although few facilities can achieve that goal, most can approach it by undercutting and finishing on the same centers or using only one setup and providing centers in the component for the spray facility to use in this operation. To determine the rotating speed for the turning fixture, the following formula can be used:

Diameter for area to be thermal sprayed = D (in inches)

Surface feet per minute = SFPM

Revolutions per minute $= \dfrac{12 \times SFPM}{\pi \times D}$

The traverse speed range for the turning fIXture is set to the parameters listed in the procedure.

When final surface preparation is completed, the component must be inspected to insure correct anchor tooth profile and that 100% of the area to be sprayed is 100% grit blasted. For more information see Preparing a Machinery Component for Thermal Spraying, Section 6, of this Manual.

Before placing the machinery component in the turning fixture, the condition of the masking must be examined, and if required (keyway masks, for example), changed to insure that no damage will be caused during or after the spraying process. When placing the component into the turning fixture, care must be taken so that the area to be sprayed is not contaminated. If handling requires touching the area to be sprayed after final surface preparation, operators must wear clean white cotton gloves. Even the normal amount of oil from human skin may cause a non-bonded area between the substrate and the bond coat.

If the component must be moved to another building or through a contaminated environment, the prepared surface should be covered to protect it from oxidation and airborne contamination. Also. to help minimize oxidation, the thermal spraying must betin within two hours after completion of the final surface preparation.

PREHEATING

After the component is placed in the turning fixture, measuring for the calculation for the expansion of the substrate material can be started. These calculations must be made because most thermal spray coatings have thickness limitations. With ceramic coatings and some metallic coatings, these thickness limitations are critical to the success of the spray application. When applying these types of coatings, the expansion of the machinery component must be taken into consideration. To calculate the expansion of the component and the diameters necessary to achieve the thickness required for the bond coat and the final coat, the formulas of TABLE 7.1 can be used. Note that these calculations are based on undercut limits which are based on the limitations of coating thickness. The final measurements for buildup calculation purposes are taken just before the first pass is sprayed.

If a component is to be sprayed without preheat, the expansion allowance must be estimated. For most single coating applications, 0.001" for every inch of component diameter (rounded to the nearest inch) provides a good ballpark number. If a more accurate value is needed, expansion tables are available which can be used to create a temperature correction curve. Contact local engineers for this information.

BUILDUP CALCULATIONS SHEET
TABLE 7.1

SYMBOLS	
C=GRIT BLASTED DIA. (AMBIENT) H=GRIT BLASTED DIA (225-250°F) E=EXPANSION ALLOWANCE B=BOND COAT GOAL DIA. S=STOP SPRAY GOAL DIA. F=FINISH DIA.	E=H-C B=F+E-O.020 S=F+E+O.020

Machinery components must never be sprayed if the substrate temperature is below 60°F or if the substrate temperature is less than 10°F above the dew point of the ambient air. The normal preheat temperature range for machinery components is 200°F to 250°F. Preheating is accomplished to remove moisture from the surface to be sprayed and may also minimize coating stress due to expansion of the component. When the plasma powder process is used, the plasma spray system can be utilized to preheat the component. If one of the oxygen fuel spray systems is used, the gas flame can be utilized for preheat. However, if preheating is done with a gas flame, the flames must never be directly applied onto the area to be sprayed (preheating the area to be sprayed directly with an oxy/fuel flame promotes oxidation of the prepared surface).

When using the arc wire spray process, most procedures permit a 60° F preheat; when preheat is required for the arc wire process, either the plasma torch or an oxygen fuel torch may be employed for preheating. Temperature sticks, or any other device that would contaminate the area to be thermal sprayed, must never be used to check the temperature of the component. A contact pyrometer is the typical instrument used by thermal spray facilities to check preheat and interpass temperature.

THERMAL SPRAYING

After preheating, the masking should be inspected again and replaced if necessary. Any masking repairs must be performed in such a way as to prevent contamination of the prepared surface. See Section 6, Preparing A Machinery Component For Thermal Spraying for further details. Masking should be monitored all during the spraying process and repaired or replaced when required. The spraying operation should only be interrupted to check temperature, measure thickness, repair or replace masking, change spraying material and parameters from the bond coat to the final coat, and to permit cooling to prevent overheating. (During spraying, the temperature of the substrate should not exceed 400°F or the tempering/aging temperature, whichever is lower.) The thermal spray operator must have sufficient training and experience to prevent excessive heat input to the machinery component. Accelerated cooling, such as a blast of clean air, carbon dioxide or other suitable gas, can be used if it is not applied directly upon the area being sprayed. Liquids must never be used for cooling the component. Once spraying starts, coating thickness per pass and the ratio of traverse rate to rpm become critical parameters. Surface speed is critical only as a starting point. If the surface feet per minute and traverse speed are initially set too slow, over-heating of the coating may take place. Applying the thermal spray material too thick per pass causes internal stresses that can lead to cracking and delamination between the layers of the coating. If the feed rate is set too fast in relation to the surface feet per minute, an uneven coating may be applied (See Figure 7.1).

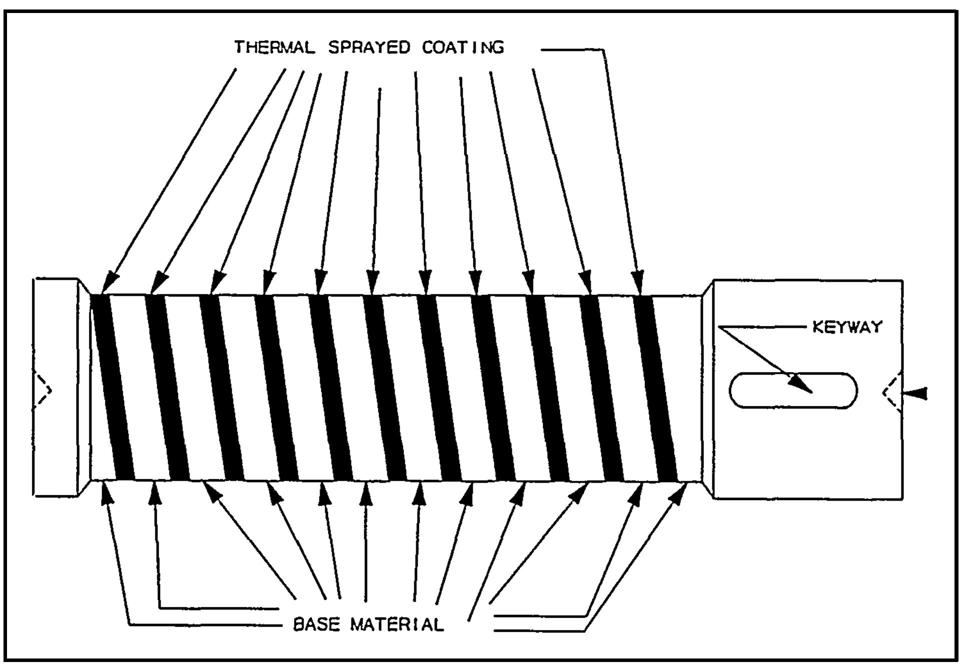


Figure 7.1 Barber Pole Effect

The thermal sprayed coating should by applied in multiple passes. Thicknesses of passes must be in accordance with the procedure for the coating system being applied. The entire area being sprayed should be coated before proceeding to the next pass. Measurements of the coating layers are required to insure the coating thickness per pass and speed and feed parameters that are listed in the procedure are being met.

If carbon inserts are used, the part must be carefully monitored to check to see if the coating is peeling from the insert. If this happens, stop and break off the coating flakes to prevent excessive shadowing of the adjacent area.

If trouble arises during the coating process, spraying must stop, and the problem must be freed. If the problem has caused a defect in the coating, the coating must be removed, and the surface blasted and thermal sprayed again.

At all times during spraying, the parameters must be monitored to insure that the procedure is being followed accurately.

COOLING & SEALING

When thermal spraying is completed, the machinery component is allowed to cool. During the cooling cycle, the machinery component should, if practical, be left rotating slowly in the turning fixture to help prevent warpage. If it is necessary to cool the component quickly, clean compressed cooling air can be used. If compressed cooling air is used, component rotation should be maintained. Compressed cooling air must be maneuvered to obtain a uniform cooling rate over the entire section. Liquids must not be used for cooling. If the component must be removed from the turning fixture, support it in a vertical position so that heat can escape evenly around the circumference of the spray zone. When the coating temperature cools to 125° F, a sealer is applied. Seal coatings must be applied in a well ventilated area. If the component is being sealed in the turning fixture, the same ventilation system used for spraying can be used during the sealing process. Phenolic resins in solution, such as Metco AP sealer, are generally used by most ship repair and ship manufacturing facilities. Sealers can be applied by using any of the common painting methods, as appropriate for the surface to be sealed.

DEMASKING

In a sense, demasking can be said to begin as soon as blasting is completed. In general, surfaces used for mounting the component are masked only for anchor tooth blasting. The rest of the masking is frequently left in place during preheating in order to help retain heat. Once spraying starts, significant portions of the masking are generally removed to aid in drawing heat away from the spray zone, thus reducing the time, required for interpass cool down. After spraying is completed, all or portions of the masking may be removed to aid cool down and/or to ease the application of sealer. The decision of when and how much masking to remove is a judgement call aided by experience. The following considerations will provide help in making these decisions.

1. A fringe benefit of masking is the physical protection provided while moving components from one place to another.
2. Removal of masking from mounting points is usually necessary after blasting in order to accurately mount the component for spraying.
3. The heat retention capability of blast masking, although limited, can sometimes significantly improve time requirements for preheat. This is especially true when the masking traps air. Component configuration and spray zone location play a significant role in this function.
4. Once preheat temperature is reached, the spray process continues to add heat to the component. Removal of some blast masking can, in some cases, significantly speed up cool down between passes as well as after spraying is complete.
5. Any procedure which uses cooling air during spraying (this includes all arc spray procedures) tends to have little or no need for auxiliary cooling.
6. Any areas which have the potential of receiving direct impact of spray material must be left masked until spraying is completed.
7. At times, application of sealer is considerably easier if shadow masks are moved away from the spray zone or removed completely.
8. Masking tape left in place during cool down generally makes for an easier job of applying sealer.
9. Tape left in place during sealing is usually easier to remove before the sealer dries.

In general, masking is removed in the opposite order of application and with little need for consideration of damage to the coating (other than common sense caution). However, a few precautions, are in order.

1. Thermal spray coatings do not holdup well to impacts; never strike the coating with a hammer or other hard tool.
2. Thermal sprayed coatings do not hold up well to point loading; never use a prybar to force a masking fixture to move.
3. If spray material should lap over masking tape, do not attempt to pull the tape directly away from the component. The sprayed coating can crack or chip back into the undercut zone, ruining the coating. Instead, chip the overlapped coating away from the spray zone as shown in Figure 7.2.
4. If spray material should lap over masking fixtures, the overlapping coating must be ground down using a hand held grinder until the fixture is freed. Do not force the grinder. Do not permit the grinder to heat spots more than warm to the touch. If at all possible, direct grinding force away from the spray zone and toward the masking fixture. Never force the fixture to move.

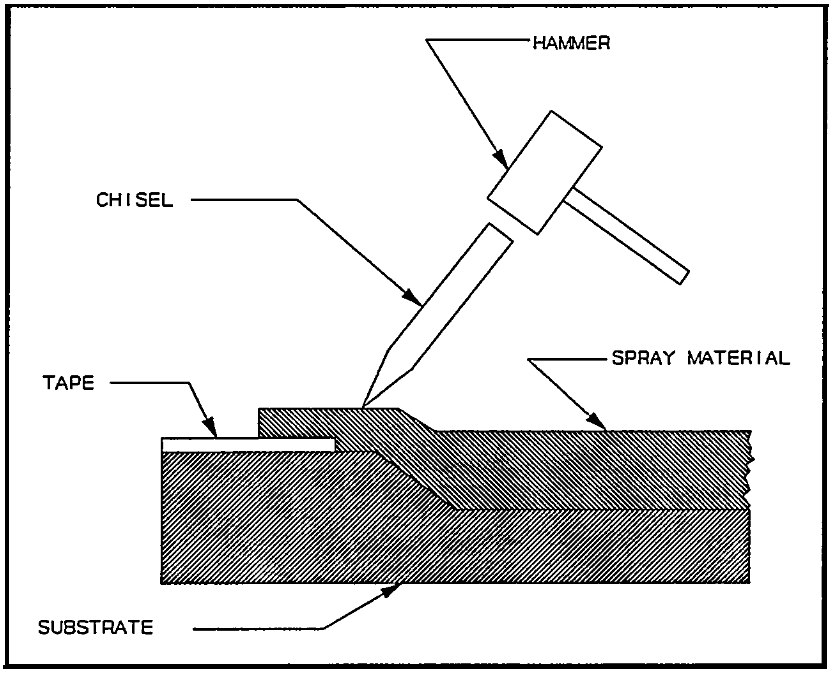


Figure 7.2 METHOD OF TAPE REMOVAL

APPENDIX 7.1

A TYPICAL PLASMA POWDER SYSTEM START UP PROCEDURE *

1. Connect and turn on gas, observing local safety requirements.
2. Install nozzle, powder port, and air jets on gun, as required by the procedure.
3. Mount thermal spray gun in the traversing gun mount, pointing it into the spray booth.
4. On the control panel, place the automatic/manual selector switch in manual.
5. On the control panel, place the Argon/Nitrogen selector switch to the gas being used.
6. Press power on button.
7. Check flows and pressures.
   Press and hold purge button.
   - a Adjust primary flow to specified level, reading flow valve at the center of the ball float.
   - c. Set the secondary flow to 27-29.
   - d. Check primary and secondary pressures at 7M control panel.
   - e. If pressure of either gas is different than specified, release purge button, adjust pressure at the gas bottle, and repeat step 7.
   - f. When pressures are correct, close secondary flow valve and maintain purge flow for 5 seconds.
   - g. Release purge button.
8. Check gun interior.
   - a. Press test button and hold it
   - b. After 5 seconds, inspect interior of the spray gun using a mirror (and wearing safety glasses).
   - c. Observe presence of high frequency arc between electrode and nozzle.
   - d. Observe that interior of spray gun and face of mirror are free of any sign of moisture.
   - e. Observe satisfactory condition of nozzle and electrode.
   - f. Release test button.
   - g. If the gun fails step 8.c, 8.d, or 8.e, correct the condition and repeat step 8.
9. Set up powder feeder.
   - a. Press auto-run/manual-standby button.
   - b. Adjust carrier gas flow to specified level.
   - c. Check powder unit for leaks.
   - d. Set spray rate control dial to specified value specified for the procedure to be sprayed.
   - e. Press auto-run/manual-standby off button.
10. Adjust secondary flow needle valves.
   - a. Open secondary flow valve 2 turns.
   - b. Press auto-run/manual-standby button.
   - c. Observe flow rate sequence.
   - d. If partial flow is 15 and full flow is 29-30, skip to step 10.i.
   - e. Close full flow needle valve.
   - f. Adjust partial flow needle valve for flow rate of 15.
   - g. Adjust full flow needle valve for flow rate of 29-30.

APPENDIX 7.1
A TYPICAL PLASMA POWDER SYSTEM START UP PROCEDURE *

h. Close secondary flow valve.
i. Press auto-run/manual-standby off button.

11. Light off spray gun and set parameters.
    a. Turn arc current control to 3.
    b. Place automatic/manual selector switch in automatic.

<WARNING>

DO NOT PERMIT SECONDARY GAS TO
FLOW WHEN THE THERMAL SPRAY GUN IS OPERATING BELOW 300 AMPS
(AFTER GUN IS LIT)

    c. Press auto-run/manual-standby button--gun should light.
    d. Dial in desired parameters manually.

NOTE

If amps and gas flows set to specified levels produce out-of-specification voltage, shut down system and replace nozzle and/or electrode. Then press power on and repeat steps 4,7,8, and 11.

    e. Press auto-run/manual-standby off button, and wait for system to cycle off.

12. Test for repeatability and smoothness of operation by lighting off spray gun and shutting down. Fine tune settings, if necessary.
13. Load hoppers(s) with desired powder.
    Thoroughly mix powder.
    a. Add powder to hopper.
    c. Test feed rate using an approved method (See Enclosure (7.l)).
14. Thermal spiny bend test and record results.

* This start up procedure is for a typical Metco 7M Plasma Powder System. Thermal spray facilities should always use their equipment manufacturer's start up procedure.

POWDER FEED RATE CONVERSION CHART

Factor (O.132) X Grams Per Minute = Lbs per Hour

Grams/Min	#/HR	Grams/Min	#/HR	Grams/Min	#/HR
1	.132	41	5.41	81	10.69
2	.264	42	5.50	82	10.82
3	.396	43	5.68	83	10.96
4	.529	44	5.81	84	11.09
5	.661	45	5.94	85	11.22
6	.792	46	6.06	86	11.35
7	.925	47	6.20	87	11.48
8	1.056	48	6.34	88	11.62
9	1.189	49	6.47	89	11.75
10	1.320	50	6.60	90	11.88
11	1.45	51	6.73	91	12.01
12	1.58	52	6.86	92	12.14
13	1.71	53	7.00	93	12.28
14	1.85	54	7.13	94	12.41
15	1.98	55	7.26	95	12.54
16	2.15	56	7.36	96	12.67
17	2.24	57	7.51	97	12.80
18	2.38	58	7.65	98	12.94
19	2.51	59	7.79	99	13.06
20	2.64	60	7.91	100	13.20
21	2.77	61	8.05	101	13.33
22	2.91	62	8.19	102	13.46
23	3.04	63	8.30	103	13.60
24	3.17	64	8.45	104	13.73
25	3.30	65	8.56	105	13.86
26	3.43	66	8.70	106	14.00
27	3.56	67	8.85	107	14.12
28	3.70	68	8.96	108	14.26
29	3.83	69	9.10	109	14.39
30	3.96	70	9.24	110	14.52
31	4.10	71	9.37	111	14.65
32	4.25	72	9.50	112	14.78
33	4.35	73	9.64	113	14.92
34	4.49	74	9.75	114	15.05
35	4.62	75	9.90	115	15.18
36	4.75	76	10.03	116	15.31
37	4.87	77	10.16	117	15.44
38	5.01	78	10.30	118	15.58
39	5.15	79	10.43	119	15.71
40	5.27	80	10.56	120	15.84

40 SECOND METHOD

1. Weigh empty container or zero the scale with empty container on the platform.
2. Collect powder in container for 40 seconds using the carrier flow rate listed in the procedure.
3. Weigh container with powder.
4. Subtract empty weight from weight with powder (Note If scale was zeroed with container on platform, this step can be skipped. This is powder weight.
5. DoubIe weight of powder.
6. Move decimal one place to the left. This is reading in pounds per hour.

60-SECOND METHOD

1. Weigh empty container.
2. Collect powder in container for 60 seconds using the carrier flow rate listed in the procedure.
3. Weigh container with powder.
4. Subtract empty weight from weight with powder. This is powder weight.
5. Multiply by .132 or use chart to determine #/HR.

EXAMPLE OF 40 SECOND METHOD:

A. Empty container weighs 15.0 grams.
B. Container with powder weigh 65 grams.
c. Container & powder = 65
   Empty weight - 15
   Result 50
   (50 is the weight of the powder.)
D. Double weight of powder. 100
E. Move decimal point one
   place to the left. = 10.0
   (10 #/HR is the spray rate.)

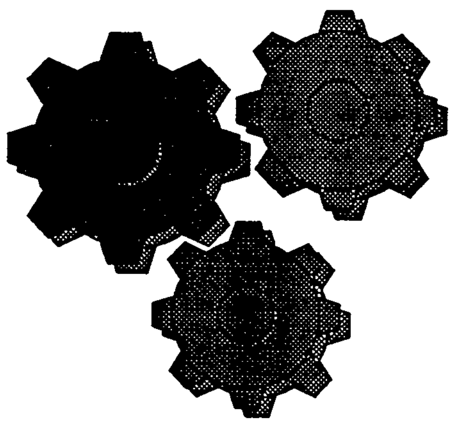
EXAMPLE OF 60 SECOND METHOD:

A. Empty container weighs 15.0 grams.
B. Container with powder weigh 91 grams.
c. Container & powder = 91
   Empty weight - 15
   Result 76
   (76 is the weight of the powder.)
   .132 X 76 = 10.032
   LBS/HR = 10.032

NOTE: On the chart, 76 Grams per Minute corresponds with 10.03 #/HR.

SECTION 8

FINISHING OF THERMAL SPRAYED COATINGS



PREPARED By: PUGET SOUND NAVAL SHIPYARD

8 FINISHING OF THERMAL SPRAYED COATINGS

INTRODUCTION

To a great extent, the effectiveness of thermal sprayed coatings is dependent upon the finishing techniques employed. The fact that the coatings are not a homogeneous mass, but rather many particles bonded together, dictates that sprayed coatings be finished with wheels and techniques or cutting tools and parameters not normally used on similar material in wrought or cast form. Also, the interposed oxides cause tool wear and grinding problems common with harder materials. This causes difficulty for machinist and machine operators who are inexperienced with the finishing of coatings. Improper machining methods can cause particle pull out, cracking, disbanding at the substrate bond coat interface, delamination between coating layers, and/or a rough finish. By carefully observing the rules governing wheel or cutting tool selection, and by employing proper grinding techniques or machining parameters, the finishing of thermal spray coatings can become relatively trouble free.

METHODS

Most thermal sprayed marine machinery components are finished by either using carbide cutting tools, high speed cutting tools, or by grinding. Wet grinding is the preferred and most common finishing method for most thermal sprayed coatings. This is especially true with hard, wear resistance coating like ceramics and carbides. When grinding these harder coatings, it is essential that the correct grinding wheel and grinding techniques are selected.

GRINDING

The American Welding Society professes that there are four general rules in grinding wheel selections. There are as follows:

1. Dress the wheel as frequently as necessary in order to use the sharpest wheel possible. Sharp wheels cut rapidly without overheating that can cause de-lamination.
2. Choose wheels with structures and grades that provide free cutting action.
3. Choose the grinding wheel bond type best suited to the operation and equipment.
4. Know the equipment - both machines and wheels,

Paramneters for grinding include the following;

1. Wheel Speed
2. Work Speed
3. Area of Contact
4. Wet Grinding
5. Wheel Dressing

RECOMMENDED GRINDING TECHNIQUES:

1. Seal the coating surface before starting the grinding process. Most shipbuilding and ship repair facilities use a phenolic sealer, such as Metco AP, for sealing thermal sprayed coatings.
2. Use softer, free cutting wheels. Chances of burnishing and particle pull-out will be greatly reduced.
3. Maintain the wheel face in a clean and sharp condition. Dress the wheel frequently to keep the face free-cutting. Grinding wheels with dull abrasive will create friction and heat.
4. Use coarse grit wheels for maximum stock removal and fine grit wheels for finishing. Attempting to generate fine finishes with coarse grit wheels that have been dressed closed can result in particle pull-out, smearing, and burnishing.
5. Use light cuts. Sprayed coatings are usually very thin. Excessive grinding pressure can cause delamination of the sprayed surface or particle pull-out.
6. Do not spark out on the final pass; this tends to glaze or dull the wheel face.
7. Grind wet whenever possible. Improved finishes, less chance of burnishing, less heat-checking, and less contamination will result.
8. Use freer grit wheels on dense, hard-to-penetrate sprayed coatings.
9. Use narrower wheels on machines with low horse-power and for more rapid stock removal of hard materials.
10. Always keep the coating under compression. By cutting down through the sprayed surface towards the substrate, delamination and particle pull-out will be minimized.
11. On encountering problems with a given wheel, experiment with wheel speeds, feed rates, work speeds, and-dressing techniques. Changes in variables can have a significant effect on stock removal rates and finishes.

Grinding wheel selection is based on the size of the component, required surface finish, hardness and structure of the coating, and the condition and capabilities of the grinding machine. Table 8.1 list grinding wheel recommendations for some of the thermal sprayed materials that are used for repairing machinery components.

TABLE 8.1
GRINDING WHEEL RECOMMENDATIONS

MATERIAL	WHEEL SPECIFICATIONS	GRINDING APPLICATION			
		CENTERLESS	CYLINDRICAL	INTERNAL	SURFACE
Alumina Chromium Oxide Titania Alumina Zirconia Titania, Yttria	Abrasive type:	C (Green)	C (Green)	C (Green)	C (Green)
	Grit size:	(180 µm)	80 (180 µm)	(180 µm)	(180 µm)
	Grade	G	G	J	F
	Bond:	Vitrified	Vitrified	Vitrified	Vitrified
	Diamond type:	Mfd Ni Clad	Mfd Ni Clad	Mfd Ni Clad	Mfd Ni Clad
	Grit size:	(120 µm)	(120 µm)	150/180 (100/83 µm)	125 (120 µm)
	Grade:	R	R	FUN	R
	Concentration	75	75	100	75
	Bond:	Reainoid	Reainoid	Reainoid	Resinoid
Chromium Cobalt Nickel	Abrasive type:	CIA	CIA	CIA	CIA
	Grit size:	(250 µm)	(250 µm)	80 (180 µm)	46 (340 µm)
	Grade:	J	J	L	H
	Bend:	vitrified	vitrified	vitrified	Vitrified
Molybdenum	Abrasive type:	C (Black)	C (Black)	C (Black)	C (Black)
	Grit size:	(250 µm)	(250 µm)	80 (180 µm)	(180 µm)
	Grade:	I	I	N	H
	Bond:	vitrified	vitrified	vitrified	Vitrified
Stainless steel (400 series)	Abrasive type:	A	A	A	A
	Grit size:	(250 µm)	(250 µm)	80 (180 µm)	(340 µm)
	Grade:	J	J	L	H
	Bond:	vitrified	Vitified	Vitified	Vitified
High nickel, alloys and Stainless steel (300 Series)	Abrasive type:	CIA	CIA	CIA	CIA
	Grit size:	(250 µm)	(250 µm)	80 (180 µm)	(340 µm)
	Grade:	J	J	J/L	H
	Bond:	Vitrified	Vitrified	vitrified	Vitrified

TOOLING

Carbide tools have been found to be very satisfactory for machinable thermal sprayed coatings. Carbides cutting tools are required for the harder materials (See Table 8.2 for carbide tools machining recommendations). High speed steel cutting tools can be used on some the softer coatings, such as brass and bronze. (See Table 8.3 for high speed single point steel tools machining recommendations.) Just as in grinding, proper tool selection and cutting parameters are critical to the final quality of the coating. See Figures 8.1 and 8.2 for tool angles for carbide tools and the recommended grind angles for high speed tool bits.

Machining of a thermal sprayed coating should start with the removal of the overspray area at the end of the coated area (See Figure 8.3.).

The rules for machining thermal sprayed coating are at follows;

1. Use a properly sharpened cutting tool.
2. Use correct speeds and feeds.
3. Use correct tool angles.
4. Use correct tool configuration.
5. Do not hog-off the coating.

NOTE After final machining has been completed, any keyway or holes that were in the thermal spray should be beveled back at the edges. This can be accomplished by using a file with a material that is harder than the thermal sprayed coating.

CONCLUSION

To assist the machinists in the finishing of thermal sprayed coatings, it is recommended that each thermal spray facility purchase a copy of the American Welding Society's "ThermaI Spraying - Practice, Theory, and Application". This publication can be ordered by calling (800) 443-9353, Ext 280. Machining parameters can also be found in the Flame Spray Handbook published by the Sulzer Metco Company.

Table 8.2
Carbide Tools Machining Recommendations

	speed (SFPM)		(IPR)	
DEPOSITED THERMAL SPRAYED COATING	Rough	Finish	Rough	Finish
Iron Base				
C .35; P .02; S .02; Mn .5; Cr 13.00; Si .5; Fe bal.	30-40	30-40	.004	.003
Mn .5; C .10; Fe bal. Mn .6; C .23; Fe ba1.	75-100 50-75	75-100 50-75	.006 .004	.003 .003
C .15; Mn 8.5; Ni 5.10 Cr 18.0; Mn .7; Fe bal.	100-125	125-175	.006	.003
C .80; Mn .7; Fe bal. C .04; Mn 2.0; Ni 4.0; Cr 1.5; Mo 1.5; Fe bal.	30-40	30-40	.004	.003
Copper Base				
Al 9.5; Fe 1.0; Cu bal.	250-300	300-350	.006	.003
Nickel Base				
Ni 95; Al 5.	200-250	250-300	.004	.002

Table 8.3
High Speed Steel Tools Machining Recommendations

BASE MATERIAL	SPEED (Surface ft) per min.	FEED (in/rev.)
Iron Base		
C .15; Mn 8.5; Ni 5.10; Cr 18; Si 1.0; Fe bal.	100-125	.003-.005
Mn .5; C 10; Fe bal.	75-100	.003-.005
C .04; Mn 2.0; Ni 4.0; Cr 1.5; Mo 1.5; Fe bal.	50-75	.003.005
Copper Base		
Al 9.5; Fe 1.0; Cu bal.	l00-125	.003-.005
99.0 + Cu	100-125	.003-.005
Cu 66; Zn 34	100-125	.003-.005
Cu 90; Zn 10	100-125	.003-.005
Cu 95; Sn 5	100-125	.003-.005
Cu 58.2; Sn .8; Fe .75 Mn .25; Zn bal.	100-125	.003-.005
Nickel Base		
Ni 67; C .15; Fe 1.5; Mn 1.0; Si .1; Al .1; Cubal;	100-125	.003-.005
Ni 99.5	100-125	.003-.005

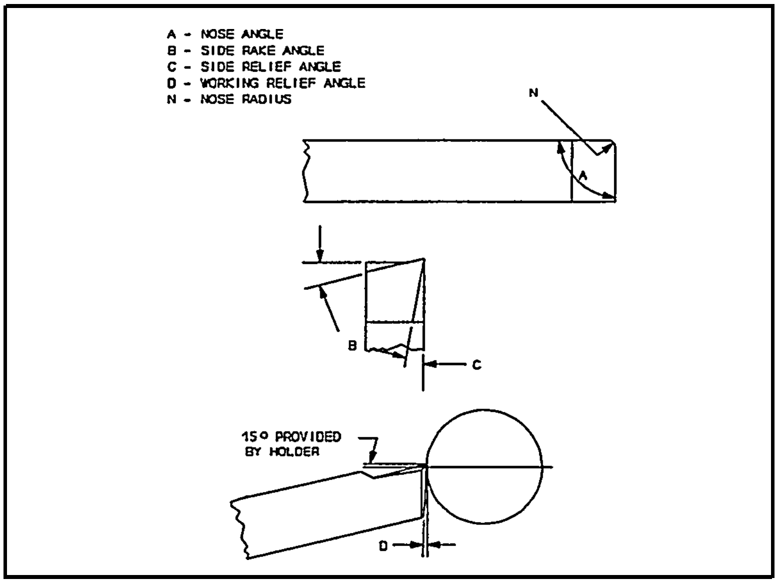


Figure 8.1 **HIGH SPEED TOOL BITS GROUND AT ANGLES RECOMMENDED FOR MACHINING OF THERMAL SPRAYED MATERIAL**

TOOL No. 1	A=80° B=0° C=10° N=0.030 in (0.76 mm)	D	
TOOL No. 2	A=80° B=10° C=10 ° N=0.030 in (0.76 mm)	D	AS LITTLE
TOOL No. 3	A=80° B=15° C=10° N=0.040 in (1.00 mun)	D	AS POSSIBLE
ALL TOOLS GROUND FOR USE IN ARMSTRONG TYPE HOLDER			

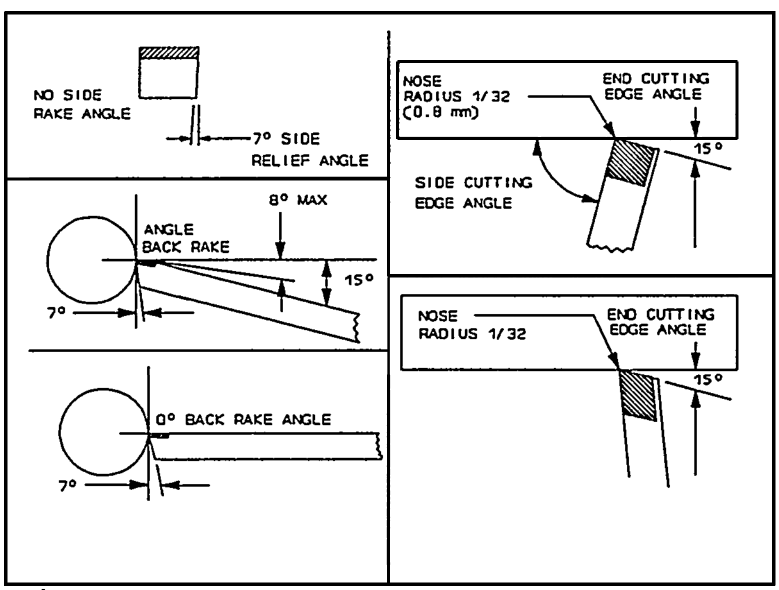


Figure 8.2 TOOL ANGLE FOR CARBIDE TOOLS

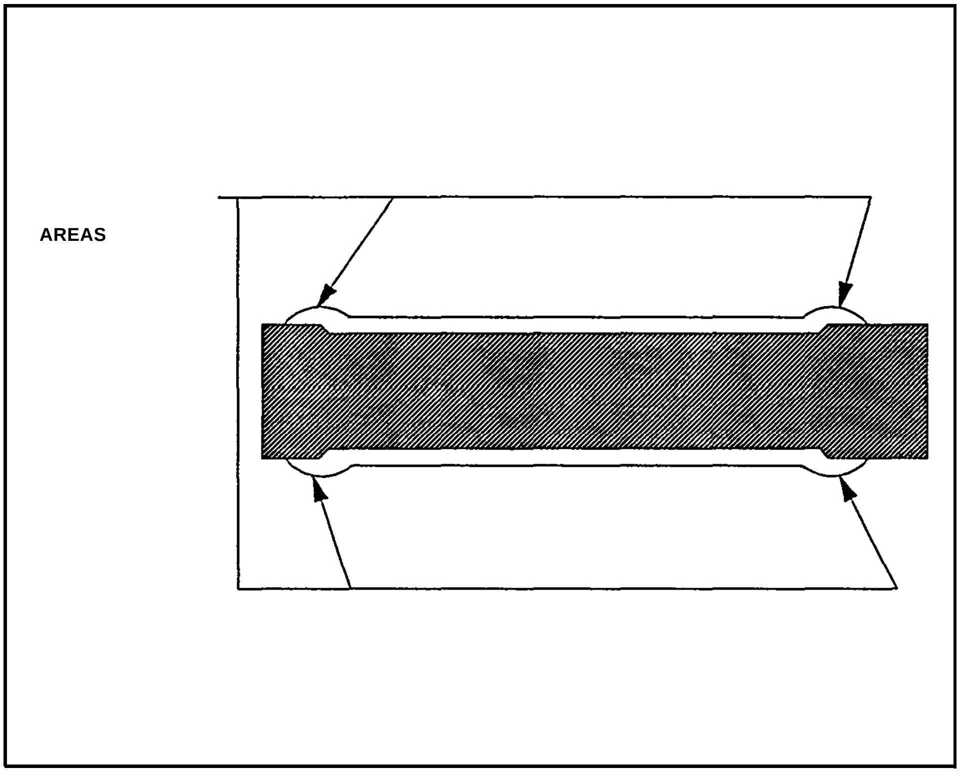
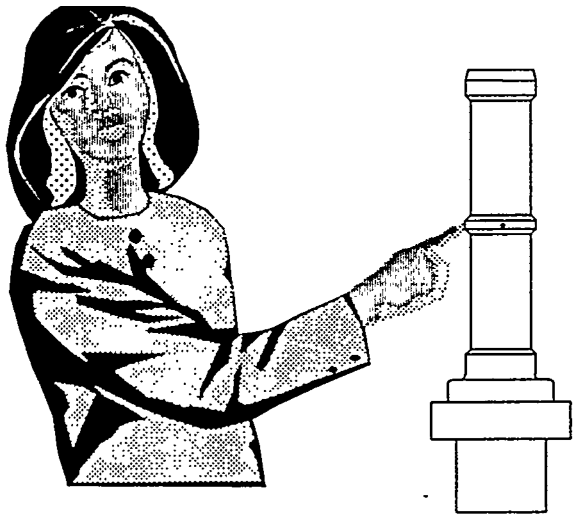


Figure 8.3 OVERSPRAY AREAS

SECTION 9

QUALITY ASSURANCE



PREPARED BY: PUGET SOUND NAVAL SHIPYARD

9 QUALITY ASSURANCE

INTRODUCTION

This section provides information to define quality and answer questions about how to achieve both quality and the assurance of quality. It also describes some of the consequences of too low priority to the process of QA. QA is the activity of providing to all concerned the evidence needed to establish confidence that the quality function is being performed adequately (from the Juran Quality Control Handbook, 3rd edition).

GENERAL REQUIREMENTS FOR QUALITY & QA

QA is not a goal or an achievement. It is a continuing process involving the entire structure of an organization. It includes procedures, the physical plant, personnel all levels, and attitudes within all of the groups involved. QA means that each member of an organization must view every step of each job as a product with a measurable level of quality; each memorandum, command decision, equipment purchase specification, or end-product affects the level of QA for the entire organization. Some areas of special concern are addressed in the following paragraphs.

QA PRIORITIES

An attitude must prevail that quality is more important than quantity. It is important to understand that this does not mean that quantity and cost is unimportant. What it does mean is that quantity without quality generally produces quantity rework.

At times, quality assurance can be confusing to the shop personnel. The quality requirements are usually specified in some corporate document referenced on an engineering instruction. Because of this, the employee gathers quality requirements mostly by word of mouth. It is rare that an employee will spend time reviewing documents to determine the quality requirements. Shop personnel will usually seek the information from a person they know who is familiar with the work. This system often works quite well, however, the process can be improved a great deal by providing this information via the work instruction. Information about inspection requirements and documentation will help the job progress and avoid costly rework. It is critical that these requirements be understood before the work commences. For quality assurance, the more detailed the information for the specific task, the easier it is for an operator to understand, and the better the job will progress. Preferably, the operator is provided with a package of specific instructions to accomplish the desired work. The operator should also know whether she/he is qualified to the appropriate standards to perform the work required.

THE COST OF POOR QUALITY

Consider the example of Widget Spray Inc. (The name was changed to protect an embarrassed company.) which thermal sprays 100 widgets per day. The company experiences an 80% reject rate. The coating is removed from the defective widgets and they are resprayed the following day as part of the regular production run. Cost to the company to spray each widget is $4.00 and to remove a defective coating is $2.00. Rework costs must be passed on to the customer, recovered in the widget sale price so rework increases production costs as follows;

$4.00 X 100 widgets per day	= $400.00
$2.00 X 80 removals per day	= m
Total per day	=$560.00

$560 ÷ 20 good widgets = $28.00 per widget
Rework cost averages $24.00 per widget

THE SAVINGS OF HIGH QUALITY

The same company embarked on a quality improvement program. Operators were retrained and procedure improvements were implemented. Spray cost were doubled to $8.00 per widget and production slowed to 50 widgets per day. Removal cost remained the same for defective widgets. However, these measures reduced the reject rate to 20%. The new production cost is as follows:

$8.00 X 50 widgets per day	= $400.00
$2.00 X 10 removals per day	= $20.00
Total per day	= $420.00

$420.00 ÷ 40 good widgets = $10.50 per widget
Rework cost averages $2.50 per widget

As the company gained experience with the new balance of quality and quantity, further improvements were made as follows:

$7.00 X 55 widgets per day	= $385.00
$2.00 X 5 removals per day	=$10.00
Total per day	=$395.00

$395.00 ÷ 50 good widgets = $7.90 per widget (354% improvement from the original)
Rework cost averages $0.90 per widget

THE MORAL

Customer relations immediately improved due to the lower costs. Further improvements in relationship gradually occurred as it became apparent that the improved quality also meant fewer after market failures. The customers now have assurance of quality.

EQUIPMENT—MAINTEN ANCE AND CALIBRATION

A primary step to producing quality work is to have equipment capable of quality production. This means performing frequent maintenance on components which affect the spray stream. As tips, nozzles, electrodes, and guides wear, they affect the temperature and shape of the thermal spray stream and the alignment of thermal spray material entering the flame. These components must be replaced frequently in order to assure that acceptable melting and proper deposit occur when the equipment is set according to established parameters. In addition, technicians must have the assurance that indicated parameters will produce the desired coating characteristics. This can be done by periodically comparing production meter readings with calibrated meters. If calibrated instruments are unavailable, an alternative method to verify acceptable parameters would be to thermal spray qualification samples using the original procedure settings and then to compare the test results to the original procedure's test results.

COATING MATERIAL-PROCUREMENT, CONTROL

The quality of a product is never better than the quality of the material used to create that product. A number of manufacturers produce high quality thermal spray materials. The competition for thermal spray feed stock helps to keep the cost of these materials relatively low. However, a spray facility must be careful to avoid the mistake of substituting other manufacturer's materials without adequate testing for sprayability. Seemingly minor variables such as powder particle size distribution can have a serious effect on coating quality. Many facilities insure their ability to obtain known quality materials by requiring a new procedure qualiflcataion when ever their procurement group purchases an alternative material. After purchase, materials must be controlled in accordance with manufacturer's instructions. These measures control quality and identity of the materials in storage and in use.

APPLICATION EXPENDABLES

To help insure a high quality coating, thermal spray facilities should use high quality gases. The following gases are recommended for use.

Gas	Specification	Type
Oxygen	BB-O-925	Commercial
Acetylene	BB-A-106	Commercial

Gas	Specification
Hydrogen	BB-H-886 Pre-purified 99.95% Maximum oxygen content 0.05%
Nitrogen	Pre-purifid Maximum oxygen content 0.002

Gas	Specification
Argon	MIL-A-18455 High purity Maximum dew point minus 76°F
Helium	BB-H-1168. grade A

Using clean, dry air is another important element in the quality assurance of a thermal spray coating. Dirty compressed air can contribute to coating defects and coating failures. The air equipment used for the abrasive blasting and the thermal spray processes should supply air having a maximum of 5 milligrams condensed hydrocarbons per cubic meter and a dew point of plus 14°F or lower at standard temperature and pressure (68°F, 14.5 lb/in^2 absolute) prior to the final faltering and moisture separation unit. Standards which apply are ASTM D 4285 and BB-A-1034.

ORGANIZATION-PERSONNEL, RESPONSIBILITY AND ACCOUNTABILITY

Quality (or lack thereof) happens in all functions and departments of an organization. It appears in the attitudes and actions of all personnel at all levels. For a Quality Assurance program to work, the following types of characteristics must exist:

1. Management must fully support Quality by providing training, proper materials and support the enforcement of standards.
2. Operation personnel must be trained to perform the work properly and to know the acceptance standards for all aspects of the tasks they perform.
3. All personnel must be dedicated to the concept of quality.
4. Responsibility and accountability for workmanship must be coupled to the product. Personnel at all levels need feedback designed to help the workers improve their performance.
5. All personnel must understand that the primary purpose of QA inspections is to assist and improve quality and productivity, not to nit-pick or look for fault.

The primary responsibility for quality assurance rests with the individual assigned to perform a work task. That individual’s skill is the frost guard against degrading the quality and reliability that was designed into the product. It is management’s responsibility to ensure that individual has the required training, information, and tools to successfully accomplish the assigned task.

SPECIFIC QUALITY REQUIREMENTS FOR THERMAL SPRAY QA

The quality of thermal sprayed coatings can be highly dependent on operator variables and parameter settings. Consequently, a variety of checkpoints for QA purposes can be a tremendous aid in maintaining a high standard of quality. Appendix 9.1 is a sample of a record-keeping procedure. It also provides check-off details which will help assure sound decisions and proper documentation for each spray job. Appendix 9.2 is a sample of an instruction for maintaining the quality of thermal spray materials. The following list summarizes the in-troduction requirements for assuring quality coatings:

1. Written records should be prepared and maintained for each sprayed component. These records should include at least the following information.

Identification of thermal spray activity.

a. Specific identification of component and system (such as, No.1 fire pump main shaft).

c. Component drawing or part number.

d. Component material (Military, ASTM, or other specification).

e. End use.

f. Job order or work number.

g. Cleaning method and method of base metal preparation (abrasive blasting, threading).

h. Sketch showing area to be thermal sprayed and undercut design.

i. Reason for thermal spraying. (wear, galling, corrosion, etc.)

j. Thermal spray process/procedure.

k. Bond and final coat material.

1. Method of surface finishing.

m. Sealant material.

n. Date sprayed.

o. Thermal sprayer's name.

p. Inspection personnel identification.

q. Acceptance standard.

2. Listing standards and specifications, (and applicable revisions), on the engineering instruction can be helpful to solve problems and answer unanticipated questions, also phone numbers of persons or departments having technical authority helps to resolve problems quickly. Most standards cover a variety of work, so it is wise to spell out the category the work fits.

3. The Thermal Spray Military Standard (MIL-STD-1687) "Thermal Spray Processes for Naval Ship Machinery Applications" requires in-process and final inspections to help assure the quality of a thermal sprayed coating.

4. Prior to commencement of each day's production, a bend test specimen should be prepared and tested to the requirements of MIL-STD-1687.

5. Before grit blasting the component should be inspected to make sure it is free of contaminants. The opemtor also should make a second check just before blasting to insure that critical areas not to be blasted are fully protected.

6. After final surface preparation (anchor-tooth blasting) the operator needs to verify the anchor-tooth profile.

7. The masking that may have been damaged during blasting should be checked to insure the critical areas that are not to be sprayed will be protected.

8. During and after thermal spraying of the component, the operator must inspect the coating for contaminants, blisters, cracks, chips, pits, or coating separation, in accordance with the requirements of MIL-STD-1687.

It is also essential that coating thickness per pass, total coating thickness, and temperature range is maintained to conform to the requirements of the procedure.

9. The finished coating must be inspected with a 10X magnification, and must be free of defects such as cracks, blisters, chips or loosely-adhering particles, excessive porosity, oil or other contaminants which bleed out through the coating, pits exposing the undercoat or substrate, and coating separation. The component must be checked for correct dimensions. These inspections fulfill the inspection requirements of MIL-STD-1687.

10. MIL-STD-1687 requires each facility using the thermal spray process for United States Naval Ship Machinery applications to have a written quality assurance system that will assure that the requirements of that Standard will be met. This written quality assurance system must contain procedures that assign responsibility and provide accountability for preforming work and inspections.

11. Handle and store thermal spray materials in accordance with recommendations of equipment and material manufacturers.

SUMMARY

It is the intent that each owner/user of the thermal spray manual will develop and insert into this section their facility's organization of technical authority for spraying specification and standards. It is recommended that document state clearly who has overall technical authority for the documents within the facility. It should also state which revision and/or notice is in effect for each standard. In some cases the authority is divided into sub-groups, for example: The Design Engineering Department may have overall responsibility and the Thermal Spray Engineers may have responsibility for the spraying sections and the Testing Division may have responsibility for the inspection section and another division may have responsibility for records.

APPENDIX 9.1
Thermal Spray
Q.A. Records Handling

1. Start Job Records.

1.1. Required Documents.

1.1.1 Insure that the Thermal Spray facility has at least two current copies of the Engineering Process Instruction.

1.1.1.1 One copy for the job package.

1.1.1.2 One copy for Thermal Spiny planning files.

1.1.2. Insure the machine shop work instruction includes a step which reads, "After Machining Call John Doe, Thermal Spray Shop at the Thermal Spray Shop phone number for visual inspection and sealing in accordance with the local process instruction (or else this facility's applicable Quality Assurance document).

1.2. Worksheet. This worksheet (See Enclosure 9.1) is designed as a Thermal Spray Job Control Record (TSJCR) scratch pad. It provides a helpful way to insure that all information is available for the thermal spray job and to take helpful notes such as special conditions, shop and engineering contacts, etc. Incidentally, the worksheet is also a good way to take notes when first contacted regarding a potential Thermal Spray Job.

1.2.1. Section I. The information required for this section is available from a variety of sources. Beginning with the most commonly utilized, they include the following;

1. Engineering written instructions.
2. Parent-shop planning office.
3. Project engineer.
4. A mechanic working the job.
5. Design prints or sketches.

1.2.2. Sketch. If available, an existing TSJCR sketch is the quickest way to get this step completed, even if it means whiting out some information or dimensions. The sketch may be roughly drawn in the space provided, or it may be immdiately drawn on one of the sketch blanks for inserting directly on the production TSJCR. For worksheet purposes, any drawing available is sufficient for noting important details and dimensions to be included in the final TSJCR sketch. Other sources for sketch information include the following:

1. Referenced drawings.
2. Engineering sketches.
3. The Component.

Note:

If the part is available, always compare it carefully with the other sources of information. Discrepancies between sources always cause less problem if they are discovered and addressed before thermal spraying starts.

1.2.3. Coating selection. Typically, coating selection is based on the standard of making the component "Better than new. "

In most cases, the selection of coating system has been determined prior to initiating the job records, and it is listed in the work documents. From time to time, this is not the case, or unusual conditions may to exist. In these cases, coating selection is based on a combination of the following sources of information:

1. Application history.
2. Consensus with thermal spray personnel.
3. Consensus with thermal spray engineers.
4. Consensus with design engineers.
5. Consensus with metallurgists.

NOTE:

For more information, see Section 5, Coating Selection.

1.3. Initiate TSJCR. (See Enclosure 9.2)

1.3.1. Assign serial number.

1. Record the number and job details in the TSJCR logbook.
2. List the number and component identification on the current progress log sheet.

1.3.2. Draw an enlarged version of the sketch on a Sketch Blank (if available, an existing sketch may be used as-is or modified).

1.3.3. Reduce/copy the sketch to fit TSJCR Section II.

1.3.4. Cut and paste reduced sketch on a blank TSJCR.

1.3.5. If the job includes a number of identical components, complete all information blocks which are identical for all pieces.

1.3.6. Reproduce enough copies to complete all pieces.

1.3.7. Fill in TSJCR #('s) and all remaining information blanks in Sections I through IV.

1.3.8. Get signatures

1.3.8.1. Foreman's concurrence in Section III.

1.3.8.2. Undercut concurrence from the Machine Shop in Block 1 of Section VI.

1.3.9. Make three copies and distribute to the following:

1.3.9.1. One extra copy for the job folder.

1.3.9.2. One copy for the thermal spray planning files.

1.3.9.3. One copy for the machine shop planning office.

2. Inspect the undercut. When the undercut component arrives from the machine shop, check compliance with sketch.

2.1. Measure undercut and record diameter on TSJCR.

2.2. Scribe TSJCR# on component.

3. Start a Job Data Sheet.

3.1. Get coating data from TSJCR. The data transferred from the TSJCR and other sources is useful in adding identification information to robot programs, performing preliminary calculations, and consolidating scratch paper functions. This improves the efficiency of the total operation.

4. Records

4.1 TSJCR (spraying)

4.1.1. Record progress on progress log as applicable.
4.1.2. During spraying, fill in Section VII.
4.1.3. After spraying, sign operator block of Section IV.
4.1.4. Return component to machine shop for finish machining.
4.1.4.1. Return all records which arrived with the component.
4.1.4.2. Retain one copy of the Material Delivery Record (MDR) which arrived with the component.
4.1.4.3. Make out new MDR using the shop identification number of the original MDR.
(a) In remarks section, write “Thermal Spray Completed”.
(b) Revise delivery locations as necessary.
(c) Fill in all other blanks per original MDR.
4.1.4.4. Keep original TSJCR at the thermal spray facility.
4.2. TSJCR (final).
4.2.1. Inspect and seal the component when machining is completed.
4.2.2. Thermal spray coating inspector sign Block 2, Section VI (inspection of finished surface).
4.2.3. Machine shop mechanic or inspector sign Block 2, Section VI (finished surface meets plan requirements).
4.2.4. Complete Sections V and VIII.
4.2.5. Review TSJCR and insure that all blanks are correctly filled out.
4.2.6. Make a copy for machinist work package (objective evidence of quality).
4.2.7. Make additional copies and file as follows:
(1) Original-- Thermal spray QA files.
(2) Copy--Thermal spray planner files.
(3) Thermal spray facility files.
(4) Copy--Records section.
(5) Courtesy copy--Originating engineer.

APPENDIX 9.2
Thermal Spray Material

1. Control.

1.1. Take reasonable precaution to protect all thermal spray material from contamination and damage. Any thermal spray material which cannot be positively identified must be discarded or returned to the manufacturer as unacceptable.

1.1.1. Storage. Store thermal spray material in a manner that will protect material identity, minimize any chance of material selection error, and comply with current hazardous material instructions. All thermal spray wire should be stored in a designated thermal spray storage unit. It should be clearly labelled and stored in boxes, plastic bags, drawers, or enclosed cabinets. Thermal spray powder, due to its form, can easily be deteriorated by contamination, especially from moisture. Therefore, the following precautions shall be observed:

1. The storage areas for sealed containers shall be warm and dry.
2. After opening, powder shall be stored in its original container in an oven maintained at 125-160”F. The cover should be placed loosely over the container opening to permit any possible moisture to escape while keeping other contaminants out.

1.2. Usage. Material issue controls maintain positive identification of spray materials and prevent inadvertent spraying with the wrong material. All material checked out for thermal spraying machinery components should be controlled by the Thermal Spray Job Control Record (TSJCR). Operators shall use only the specific material listed on the TSJCR. Before use, inspect material for cleanliness and usability.

1.2.1. Thermal Spray Wire. During the spraying process, operators should protect the wire from contamination. Periodic visual inspection of the wire shall be accomplished to help insure the cleanliness of the material. Thermal spray wire must be returned to the appropriate storage area under any of the following conditions:

1. The wire feeder is secured and placed in storage.
2. The wire feeder is moved to another work site.
3. A new job requires a different type of wire.

1.2.2. Thermal Spray Powder. Before use, thermal spray powders must be inspected for usability. Powders must be free of clumps that would inhibit their flow through feed lines. To help insure the creation of a high quality, when using thermal spray powder, the following are good “Rules of the Road”:

1. When falling powder feeders, remove covers from only one powder container and one powder hopper at a time. This step helps to prevent mixing of different types of powder when two or more types of powders are required for a single specific job.

2. When setting up for a thermal spray job, check equipment and spray material for signs of contamination. Discard all contaminated powder and completely clean a contaminated powder feeder before filling the powder hopper.
3. If the job permits, run the powder feeder hopper completely empty before adding powder from a newly opened container.
4. Drain powder into its original container and blow down hoses and interior of powder feeder when securing the spray equipment or when changing types of powder.
5. Thoroughly mix the powder by rotating the container end-over-end before loading the powder hopper.
6. Take all necessary precautions to keep powder dry and to prevent stratification of particles by size in the powder hopper. This is best done by keeping all containers and hoppers tightly closed (except when filling hoppers) while out of the oven and by returning all unused powder to the oven within 8 hours after loading a powder feed hopper.

1.3. Identification.

1.3.1. Check labels to insure that the thermal spray material is the exact material (size, type, grade, etc.) specified for the job.

1.3.2. Maintain positive identification of all spray material.

1. Thermal spray powder and wire used as a spray material must be identified and controlled.
2. All other thermal spray material must be clearly labeled on each unit of issue. The labels must include the following:
   Manufacturer.
   a. Manufacturer's trade name and/or generic identification.
   c. Size, or size designator, if applicable.
   d. Lot number or heat identifiation.
   e. NFPA label, with information as provided from the MSDS.

THERMAL SPRAY JOB CONTROL RECORD (TSJCR)

SERIAL No.

SECTION I JOB DATA	JOB ORDER NUMBER	SHIP/PROJECT	OPERATING MEDIUM
	FOREMAN/SHOP	PHONE	MECHANIC/SHOP
	PART DESCRIPTION		DRAWING NO.
	FUNCTION OF COATING	BASE MATERIAL/ALLOY/MIL SPEC/ETC	SCHED DATE
	REASON FOR SPRAYING	SHIP SYSTEM	
SECTION II PREPARATION			

SECTION III SPRAYING SHOP	PROCEDURE I.D. (APP OR MWP#)	SEALER TYPE	SECTION IV APPROVALS	AUTHORIZING DOCUMENT IDENTIFICATI
	BOND COAT MATERIAL/PROCESS			MIL-STD-1687A
	FINISH COAT MATERIAL/PROCESS			
	S/26 OPERATOR (SIGNATURE)	DATE	SECTION V FINAL MACHINING	FINAL MACHI TOOLING USE GRIND ☐ T
	S/26 FOREMAN (SIGNATURE)	DATE		

SECTION VI VERIFICATION SIGNATURES	1. TSJCR UNDERCUT INSTRUCTIONS MEET EPI REQUIREMENTS	(Signature)(S/31)
	2. MACHINED PREPARATION IS IN ACCORDANCE WITH SKETCH	(Signature)(S/26)
	3. INSPECTION OF FINISHED SURFACE (RESULTS FOUND IN SECTION VIII)	(Signature)(S/26)
	4. FINISHED SURFACE CONDITION MEETS PLAN REQ. FOR SIZE, SURFACE COND.	(Signature)(Lead Shop)

SECTION VII SPRAY DATA	METHOD OF SURFACE PREPARATION ☐ ALUMINUM OXIDE BLASTING ☐ THREADING ☐ OTHER (SPECIFY): ____________	SECTION VIII INSPECTION	INSPECTION METHODS USED: ☐ VISUAL ☐ SAT ☐ UNSAT ☐ DIMENSION ☐ SAT ☐ UNSAT ☐ THERMAL WAVE NDE ☐ SAT ☐ UNSAT ☐ OTHER (SPECIFY):__________ ☐ SAT ☐ UNSAT
	ANCHOR TOOTH HEIGHT (MILS) 3.3		ACCEPTANCE STANDARD: ☐ PROCESS INSTRUCTION ☐ OTHER (SPECIFY):_________ REM
	BOND COATING THICKNESS APPLIED N/A		
	FINISH COATING THICKNESS APPLIED .028		
	TOTAL COATING THICKNESS APPLIED .028		

THERMAL SPRAY JOB CONTROL RECORD (TSJCR)

THERMAL SPRAY JOB CONTROL RECORD (TSJCR)	SERIAL No.	REF

SECTION JOB DATA

JOB ORDER NUMBER	SHIP/PROJECT		OPERATING MEDIUM	
FOREMAN/SHOP	PHONE	MECHANIC/SHOP		PHONE
PART DESCRIPTION			DRAWING NO.	PC. NO.
FUNCTION OF COATING	BASE MATERIAL/ALLOY/MIL SPEC/ETC			SCHED COMPL DATE
REASON FOR SPRAYING	SHIP SYSTEM			

SECTION U PREPARATION

SECTION III SPRAYING SHOP

PROCEDURE I.D. (APP OR MWPb)	SEALER TYPE	SECTION IV APPROVALS	AUTHORIZING DOCUMENT IDENTIFICATION MIL-STD-1687A
BOND COAT MATERIAL/PROCE5S			
FINIsH COAT MATERIAL/PROCESS			
S/26 OPERATOR (SIGNATURE)	DATE	SECTION V FINAL MACHINING	FINAL MACHINING TOOLING USED: ORIND ❑ TOOLING ❑
S/26 FOREMAN (SIGNATURE)	DATE		

SECTION VI VERIFICATION SIGNATURES

1. TSICR UNDERCUT INSTRUCTIONS MEEI EPI REQUIREMENTS	(Signature)(S/31)	DATE
2 MACHINED PREPARATION IS IN ACCORDANCE WITH SKETCH	(Signature)(S/26)	DATE
3. INSPECTION OF FINISHED SURFACE (RESULTS FOUND IN SECTION VIII)	(Signature)(S/26)	DATE
4. FINISHED SURFACE CONDITION MEEKS PLAN REQ. FOR SIZE, SURFACE COND.	(Signature)(Lead Shop)	DATE

SECTION VII SPRAY DATA

METHOD OF SURFACE PREPARATION
❑ ALUMINUM OXIDE BLASTING
❑ THREADING
❑ OTHER (SPECIFY): ___________
ANCHOR TOOTH HEIGHT (MILS) 3.3
BOND COATING THICKNESS APPLIED N/A
FINISH COATING THICKNESS APPLIED .023
TOTAL COATING THICKNESS APPLIED .028

SECITON VIII INSPECITON

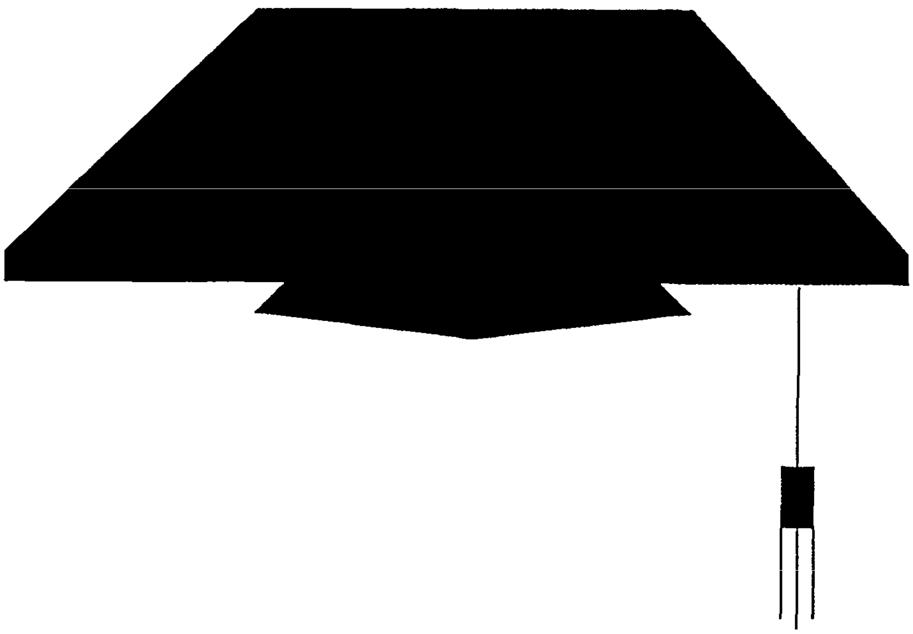
INSPECTION METHODS USED:

❑ VISUAL	❑ SAT ❑ UNSAT
❑ DIMENSION	O BAT ❑ UNSAT
❑ THERMAL WAVE NDE	❑ SAT ❑ UNSAT
❑ OTHER (SPECIFY):_________	❑ SAT ❑ UNSAT

ACCEPTANCE STANDARD:
❑ PROCESS INSTRUCTION ❑ OTHER (SPECIFY):_________ REMARKS:

SECTION 10

TRAINING AND CERTIFICATION



PREPARED BY: PUGET SOUND NAVAL SHIPYARD

10 TRAINING AND CERTIFICATION

INTRODUCTION

Consistent production of quality coatings requires the following:

1. Qualified operators who are skilled, knowledgeable, and highly motivated.
2. A properly outfitted facility.
3. Equipment in a good state of maintenance.
4. Spray material correct for the job and properly stored and handled.
5. Specific procedures which have been tested and qualified for each coating system.
6. An administration which supports the measures necessary to maintain quality.

Of the six requirements, operators are by far the most critical. In most facilities operators are the first line of control for most of the listed requirements. Operators influence outfitting by specifying current and future requirements. Operators control most maintenance and perform much of it themselves. Operators have the responsibility for storage and control of most thermal spray material. Operators are accountable for controlling each detail of any procedure used at the facility.

OPERATOR TRAINING

Prospective operators must be trained in general theory and the application of coating systems (See Appendix 10.1). They must learn and practice proper techniques in surface preparation, coating processes, spray equipment operation, and turning fixture setup. They must be or become safety-oriented. They must learn how and when to apply sealer. Operators must gain an understading of finishing techniques. Finally operators must become quality control personnel, able to identify and reject substandard coatings (See Appendix 10.2).

TABLE 10.1
INTRODUCTORY TRAINING RECOMMENDED

	CLASSROOM (HRS)	ON JOB TRAINING (HRS)
[1]BASIC OPERATOR TRAINING	10[2]	10[2]
[1]Q/A INSPECTOR TRAINING	6[2]	0
PROCESS TRAINING		
PLASMA POWDER	20[2]	80[2]
ARC WIRE	o	20[2]
FLAME POWDER	o	40[2]
FLAME WIRE	o	40[2]
HIGH VELOCITY OXY/FUEL	20	20

[1]PREREQUISITES FOR PROCESS TRAINING
[2]MIL-STD-1687 MINIMUM TRA1NING REQUIREMENTS

Specific training is essential on processes and equipment in order for thermal spray operators to become skilled at their trade (See Appendices 10.3 - 10.7). TABLE 10.1 is the recommended minimum training time. These times are based on experience and by Military Standard 1687 to achieve introductory level skills. Note that basic operations and quality assurance training are required prior to learning any of the speccific processes.

OPERATOR TESTING

Due to the critical nature of the operator's control of the thermal spray process, facilities must provide some level of operator certification. This is usually accomplished by requiring all operators to demonstrate knowledge, skill through testing, and have a specified number of hours of on the job training.

KNOWLEDGE TESTS

Military Standard 1687 requires that operators demonstrate knowledge about thermal spray by passing two written tests. The first is an operator test, demonstrating general knowledge about theory, processes, related equipment, operating and setup procedures, and safety issues (for a sample test, see Appendix 10.1). The second is the quality assurance inspector test, which covers qualities of a good coating, conditions which cause or indicate an unsatisfactory coating, and the understanding and use of quality assurance tools. (For a sample test, see Appendix 10.2) These tests have been approved by the Naval Sea Systems Command and have been used in the qualification testing of operators currently certified to conduct thermal spiny operations on machinery components for the United States Navy.

PERFORMANCE TESTS

After training, thermal spray facilities must confirm the performance skill of their operators by requiring them to complete the following examinations;

- ☐ **MOCKUPS:** Thermal spray operators must be able to demonstrate their ability to select the correct thermal spray parameters and to successfully set up and operate the turning fixture and thermal spray equipment. The operator must be able to demonstrate the ability to control thermal spray parameters, temperature, and thickness per pass. A turning future and thermal spray equipment is used to spray a mockup of a machinery component to demonstrate these skills (See Figure 10.1).

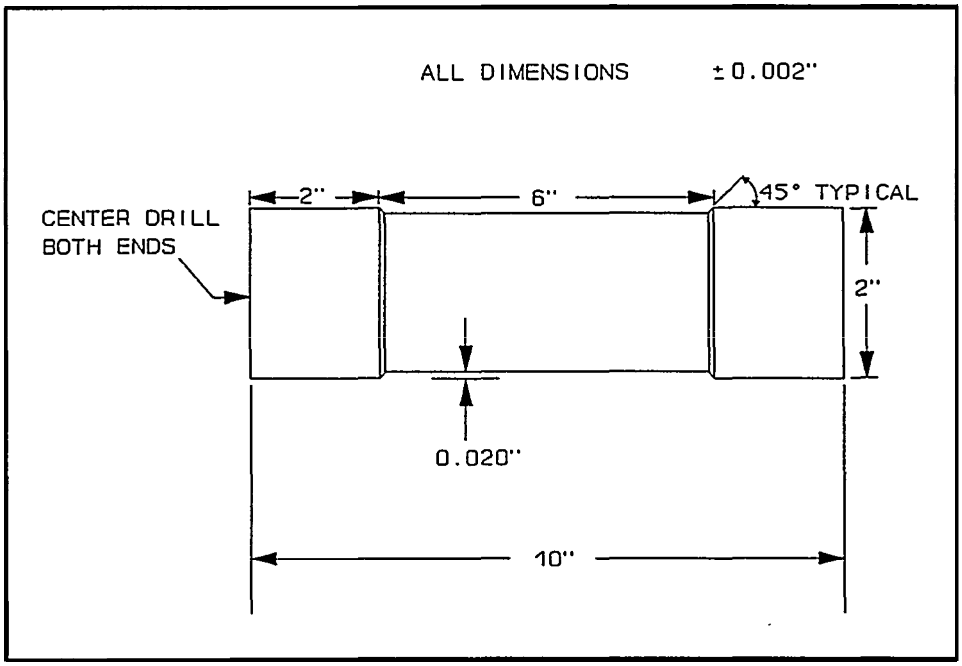


Figure 10.1 OPERATOR PERFORMANCE TEST MOCKUP

- **DESTRUCTIVE TEST SPECIMENS:** Thermal spray operators should be able to satisfactorily complete spraying of appropriate test specimens. These specimens will determine the quality of coating by being tested for bond strength and for oxides and porosity content. The United States Navy has developed bond strength and oxide/porosity requirements for operators who are to repair machinery components for Naval Ships. These requirements include thermal spraying tensile coupons (Figure 10.2), bend plates (Figure 10.3), and plates for visual and microscopic examination. (See TABLE 11.1 in Section 11 for minimum test requirements.) Section 11 also contains complete information on performance testing for operator and procedure qualifications.

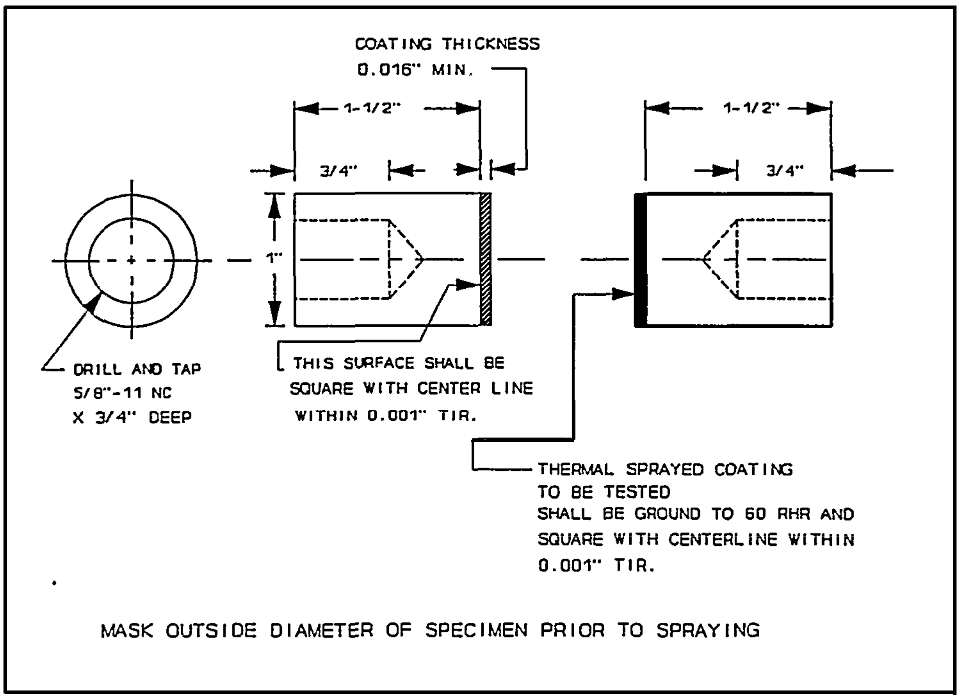


Figure 10.2 TENSILE PULL BUTTONS

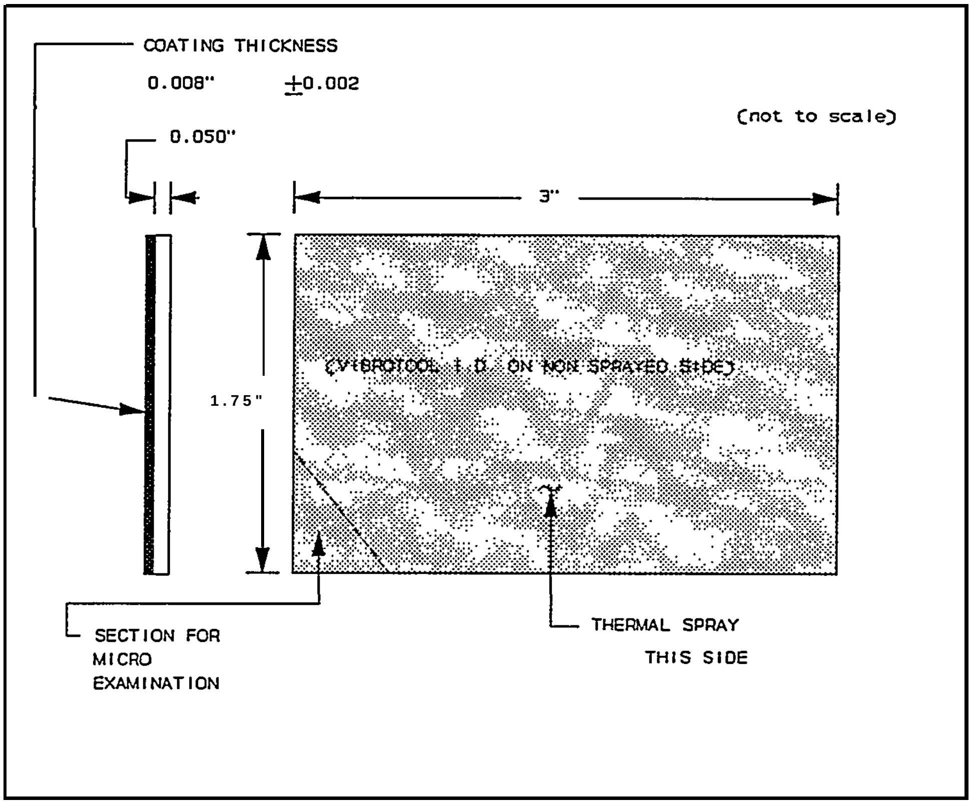


Figure 10.3 VISUAL, BEND, AND MICROSCOPIC EXAMINATION PLATES

INSPECTOR TRAINING AND TESTING

Thermal spray coating inspectors should be given at least six hours of classroom instruction on the general theory, application and coating processes, and quality assurance. This training should include hands-on training with the inspection tools used to check the quality of a coating and examples of good and bad coatings on representative parts. An example of the type of written test that can be used is found in Appendix 10.2. Like the operator test, this test has been approved by the NavaI Sea Systems Command.

SUMMARY

For training of thermal spray operators, use the other sections in this manual as the basic source of information for the training courses described in the appendices to this section. These appendices include a reference section for additional information as necessary. The following outlines provide overviews of courses of instruction for workers who are entering or advancing in the field of thermal spray.

APPENDIX 10.1	BASIC THERMAL SPRAY OPERATOR, MACHINERY REPAIR
APPENDIX 10.2	THERMAL SPRAY QUALITY ASSURANCE INSPECTOR
APPENDIX 10.3	PLASMA POWDER PROCESS OPERATOR
APPENDIX 10.4	ARC WIRE PROCESS OPERATOR
APPENDIX 10.5	FLAME POWDER PROCESS OPERATOR
APPENDIX 10.6	FLAME WIRE PROCESS OPERATOR
APPENDIX 10.7	HIGH VELOCITY OXYGEN FUEL PROCESS HVOF OPERATOR

Appendix 10.1
Basic Thermal Spray Operator, Machinery Repair

I. COURSE DESCRIPTION. The following outline is a sample for a twenty-hour training course, designed as an introduction to thermal spray for operator trainees. Approximately half of the course will be spent in the classroom introducing thermal spray concepts and safety procedures and taking a written test. The other half of the course is spent in the shop practicing the introductory level operations involved in producing a thermal sprayed coating on a simple shaft mock up.

I I OBJECTIVES. Trainees who successfully complete this course should be able to do the following:

A. Understand and comply with applicable safety and environmental procedures.
B. Understand and apply the basic principles of thermal spray.
c . Describe five of the predominant thermal spray processes in current industrial use.
D. Select a coating and design the undercut for an application or mockup described by the instructor.
E. Display familiarity with component and surface preparation methods.
F. Demonstrate the ability to set up and spray a rotating machinery component.
G. Be able to monitor and correctly adjust coating parameters while spraying with one of the processes described in this course.
H. Demonstrate the ability to differentiate between acceptable and unsatisfactory surface preparations and as sprayed and machined coatings.
I. Pass a written test on the various knowledge aspects described in the outline of this course.

III. **PREREQUISIES.**

A. This course is designed for people who already have a background of knowledge and practice in the following areas:
   1. Safe use of manual plasma arc cutting equipment.
   2. Safe use of inert gas.
   3. Safe use and techniques for operating lathes or similar machining equipment.
   4. Proper use of respirators suitable for typical welding operations.
   5. Safe use of oxy/fuel burning equipment.
   6. Back injury prevention.
   7. Proper practices for hazardous material storage, usage and disposal.
   8. General safe work practices in a shop environment.
B. Prospective trainees who lack a background in any of the above categories must receive training in those areas. This training must include, at the very least, information and practice which apply to the thermal spray equipment and to activities the trainees can be expected to encounter in the thermal spray shop.
c . Jaeger eye test - See Military Standard 1687, paragraph 4.4.2.4.

IV. **HANDOUTS.** Trainees should be provided with the following material for reading and classroom work:

A. **NATIONAL SHIPBUILDING RESEARCH PROJECT** "Thermal Spray Manual", by Puget Sound Naval Shipyard, 1996

B. **THERMAL SPRAYING,** Practice, Theory, and Application; American Welding Society, Miami, 1984

c. Recommended Safe Practices for Thermal Spraying, AWS C2.1, American Welding Society, Miami *

* American Welding Society Publications are available for a fee from AWS in Miami, Florida. Phone (800) 443-9353, Ext 280.

V. **COURSE OUTLINE.**

- A. Introduction
  1. Course objectives
  2. History
  3. Introduction to thermal spray principles
  4. Definitions
  5. Thermal spray video
- B. Safety
  1. General safety review (Including Personal Protective Equipment)
  2. Compressed gases
     - a. Air
     - b. Oxygen
     - c. Fuel gases
     - d. Inert gases
     - e. Hook-up and break-down procedures
  3. Grit blasting hazards
  4. Spray equipment operation
     - a. Electric shock
     - b. Fire and explosion hazards (Including flashbacks)
     - c. Noise hazards
     - d. Ultraviolet hazards
  5. Hazardous materials
     - a. Storage
     - b. Handling
     - c. Disposal
- C. Thermal spray equipment
  1. Processes and the guns
     - a. Essential components
     - b. Energy supply
       - (1) Type (Fuel or electricity)
       - (2) Amount required
     - c. Important characteristics
- D. Auxiliary equipment
  1. Turning machinery

2. Ventilation
3. Hand tools

E. Materials
1. Identification and characteristics
   a. Substrates
   b. Coating (thermal spray) materials
   c. Solvents
   d. Sealers
2. Storage
3. Coating selection process

F. Thermal spray process
1. Overview
   a. Sequence
   b. Quality Assurance/Records
2. WorkPiece preparation
   a. Cleaning
   b. Undercutting/Design/Records
   c. Masking
   d. Surface preparation (anchor tooth blasting)
3. Spraying the component
   a. Parameters
   b. Equipment setup
   c. Calculations and control of deposit
   d. Records
4. Post-spray treatment
   a. Cool down
   b. Demasking
   c. sealing
   d. Machining
   e. Final inspections
   f. Records

G. Testing of coatings
1. Coating structure
2. Qualification/ Acceptance Testing
3. Visual inspection standards
   a. In-process inspection
   b. End-item inspection
   c. Coating imperfections
   d. Consequences of improper parameters
   e. Consequences of attempts to cover flaws

H. Hands-on training (mockup)
1. Safety review
2. Cleaning practice
3. Masking practice
4. Surface roughening methods and standards

a. Anchor tooth profile
b. "White metal" standards
5. Component handling
6. Equipment practical experience
a. Startup
b. Setup
c. spraying
d. Shutdown
e. Maintenance
7. Spiny practice
a. Assess surface preparation
b. Handle or mount workpiece
c. Control spray and hardware parameters
d. Take in-process quality assurance measurement
e. Apply applicable sealer(s)
f. Perform, or prepare mockup for, finish machining
g. Acceptor reject finished coating

VI. **VISUAL AIDS.** Instructors may use the figures in this Manual to produce overhead transparencies as necessary for illustrating the various aspects of the thermal spiny process. In some cases, local equipment can be expected to vary from the included figures enough to cause confusion. In these cases, the purposes of this instruction would be better served by using locally available material to generate appropriate visual aids.

VII. **REFERENCES.** Additional material is available for further information about the various aspects of the thermal spray processes. A variety of literature is listed in the reference sections of the books used for this course. (Specifically American Welding Society's "Thermal Spraying - Practice, Theory, and Application" 1985, and AWS C2.1 "Recommended Safe Practice for Thermal Spraying" are recommended for purchase.

VIII. **TRAINING AIDS AND PRACTUCE MATERIALS** (These may be prepared by the instructors or ordered from a facility with competent operators).

A. Surface preparation samples as follows:
1. Surface blasted with ball shot to provide clean surface but without angular profile.
2. Surface blasted for too short a time, leaving excessive contamination. (Near white metal calls for a maximum of 5% visible rust contamination, without oil, grease, dirt, and loose material or grease.)
3. Surface contaminated with oil, grease, dirt, and loose material or dust.
4. Surface blasted correctly, giving a clean near-white or white metal surface with an angular profile appropriate to the coating type. The surface as prepared must be free of dust arising from other spraying operations, broken down blast media, etc.

B. Mockup shafts and required masking materials (1 per trainee).
C. Sample shaft with keyway.

D. Hand tools and spray equipment.

IX. **TESTING.**

A. Thermal spray operator written test. One set of test questions approved by NAVSEA follows on Page 6.

THERMAL SPRAY OPERATOR
WRITTEN TEST

1. What are the heat sources for the following thermal spray processes?
   (a) plasma powder
   (b) arc wire
   (c) flame powder
   (d) flame wire
2. What is the difference between interface bond and interparticle bond?
3. Is a coating sprayed at 45° to the surface of a component the same as a coating sprayed at 90° to the surface of a component? Which is best?
4. One of the major reasons for a poorly bonded coating is incorrect spraying parameters. What is the other major cause?
5. How is the coating density affected by the speed of the molten spray particles?
6. Why are substrates preheated before thermal spraying?
7. What are two purposes for applying a bond coat?
8. Argon, Nitrogen, or Hydrogen can be used as carrier gas? True____ False_____
9. How many people should be present during the spraying operation?
10. Why should shafting be undercut and finished on the same centers?
11. If something happens to coating during the process, it is permissible to spray over visible coating defects. True____ False_____
12. When grit blasting a machinery component for surface preparation before flame powder spraying, why is aluminum oxide grit used instead of steel shot?
13. Why should thermal spraying begin within 2 hours after blasting?
14. Why must the surface of the component be free of (oil, grease, tape glue, etc.) before and after grit blasting.
15. In what temperature range is it best to apply Metco AP sealer?
16. Why are thermal sprayed coatings sealed?
17. Name 5 things that would cause a thermal spray coating to be rejected.
18. What safety precautions should be taken when operating a turning fixture or lathes?

B. Answer key for written test

ANSWER KEY

1. (a) Plasma arc
   (b) Electric arc
   (c) Oxygen fuel flame
   (d) Oxygen fuel flame
2. Interface refers to the bond between the surface of the substrate and the spray material. Interparticle refers to the bond between the splats.
   Note: Zone between two different coatings is normally considered an interface.)
3. No. - 90° The angle of spray impingement to the work surface has a pronounced effect on the physical properties and structure of the coating. When spraying at a steep angle a shadow effect may result.
4. Poor surface preparation.
5. Increasing the speed of the molten spray particles increases the density of the coating
6. To remove all surface moisture and to expand the substrate to reduce residual tensile stress during cooling.
7. To improve the bonding of the final coat to the substrate and for build up.
8. False - hydrogen is a fuel gas and can not be used as a carrier gas.
9. Two.
10. To insure the finished coating thickness is concentric with the part.
11. False.
12. Aluminum oxide grit will create the anchor tooth pattern that is required on the surface of the component. Steel shot will not.
13. After two hours excessive oxides will start to form on the component's surface.
14. (a) Grit blasting may not remove all the contamination from the component's surface.
    (b) Contamination will adversely affect the coating bond.
15. 100° F to 125° F - in this range sealer penetrates better due to the better viscosity.
16. To improve machining of the coating and to seal the porosity pores.
17. Blisters, cracks, uneven coating thickness, excess porosity, chips or loosely adhering particles, evidence of oil or other contaminants, pits exposing the bond coat or substrate, coating separation, spatter or unmelted particles.

18. Do not wear loose clothing, gloves, or long hair that can be caught in the turning chuck or other mechanisms.

C. Performance Test Mockups

For performance testing, operators should spray at least one mockup in accordance with the description on page 10.2 of this manual.

Appendix 10.2
Quality Assurance Inspector

I. **COURSE DESCRIPTION.** The following outline is a sample for a thermal spray training course for Quality Assurance Inspectors. This is a six hour course designed to give thermal spray operators and supervisors the knowledge and skills required to conduct final acceptance inspections on thermal sprayed components and to enhance the skills as required for conducting in-process inspections and performing other related Quality Assurance functions. The course includes hands-on training with inspection tools and workmanship samples and concludes with a written test.

II. **0BJECTIVES.** Trainees who successfully complete this course will be able to perform the following objectives:

A. Be familiar-with the record keaing requirements of MIL-STD-1687 and this thermal spiny facility.
B. Be familiar with the acceptance standards associated with each stage of the thermal spray process.
c . Demonstrate the ability to locate and identify the various kinds of defects which may be encountered in a thermal sprayed coating.
D. Assess the quality of the coating on one or more finished workmanship samples and accept or reject the coatings(s) on the basis of that assessment.
E. Display a basic understanding of the theory, applications, and SPrAY methods associated with the thermal spray process.

III. PREREQUISITES.

A. Jaeger eye test for welders
B. A commitment to quality which is strong enough to reject a marginally unsatisfactory coating even when under pressure from time constraints or management.

IV. HANDOUTS. Trainees will be provided with the following material for reading and classroom work:

A. Thermal Spray Handbook, Section 9, Quality Assurance
B. Thermal Spraying; Practice, Theory, and Application
C. MIL-STD-1687
D. Local process instruction (or comparable document for controlling local work practices and procedures).

v . COURSE OUTLINE.

A. Introduction - read introductory statement for this appendix.
   1. Course objectives - see item II (above).
   2. Definitions
      a. Thermal Spray - (AWS definition as quoted in MIL-STD-1687)
      b. Quality Assurance - (Thermal Spray Manual Definition)
      c. Quality - (Thermal Spray Manual Definition)
      d. Malpractice - (Thermal Spray Manual Definition)

e. Others can be found as needed in referenced works (See VI, below)

3. The purposes of Quality Assurance and Quality Assurance Training.
   a. Provide reasonable assurance that sprayed coatings will not fail in service.
   b. Aid in determining potential causes if failures do occur.
   c. Provide clear communication of requirements in order to aid in assuring that a job is done right the first time.
   d. Quality Assurance Manual (definitions and T/S related information)

B. Review of Thermal Spray Basics
1. The five significant thermal spray processes, including an emphasis on the sources of heat.
2. The general types of coatings available.
3. An overview of thermal spray applications.
4. A review of general shop safety and the specific safety practices which apply to Quality Assurance.

C. Introduction to controlling documents
1. Overview - See TABLE 9.1 in the Quality Assurance section of this Manual for a cross-reference between the three documents used in this training course.
   a. MIL-STD-1687 controls quality assurance training and emphasizes facility and management practices for United States Naval applications.
   b. Local process instruction or comparable document for controlling local work practices and procedures.
   c. The Quality Assurance Section of this Manual.
   d. Main points of comparison/contrast
      (1) The MIL-STD controls Quality Assurance training and emphasizes the requirements for controlling facility and management practices.
      (2) The process instruction is the written procedure required by MIL-STD-1687. It is the controlling document for work practices and inspection standards.
      (3) Other plans such as the Quality Assurance records plan in the Quality Assurance handout may be used to give additional guidance. Caution must be advised, since this type of plan does not supersede process instruction or MIL-STD requirements.
   e. Review general contents of the documents presented above.
2. Facility and procedural cetification
3. Operator qualification and testing
4. Production quality assurance
   a. Follow the written plan/procedures
   b. Maintain quality assurance records
   c. In-process monitoring, inspections, and acceptance standards
   d. Final inspections and acceptance standards

D. Practical experience/production sequence
1. Records initiated for each component to control entire process.

2. First inspection-Undercut
   a. Measuring tools and how to use them
   b. Handling do’s and don’ts
   c. Inspection checklist
   d. Acceptance standards
   e. Potential defects and imperfections
   f. Corrective action/Avoiding malpractice
3. Second inspection - Anchor tooth surface preparation
   a. First of two major causes of bond failure (poor cleaning/blasting)
   b. Effects of handling
   c. Measuring tools and how to use them
      (1) Workmanship samples
      (2) Profile tape
      (3) Dial micrometer
      (4) Micrometer or vernier caliper
   d. Anchor tooth profile
   e. Inspection check list
   f. Acceptance standards
   g. Defects, imperfections and causes for coating failure
   h. Time limits
   i. Corrective actions/avoiding malpractice
4. Third inspection - In-process monitoring of spraying
   a. Second of two major causes of bond failure (poor thermal spray parameters)
   b. Coating structure
   c. Time limits
   d. Effects of handling
   e. Measuring tools
      (1) Workmanship samples
      (2) Micrometer or caliper
      (3) Pyrometer
   f. Inspection checklist
   g. Acceptance standards
   h. Defects, imperfections and causes for coating failure
   i. Corrective action/Prevention of malpractice
5. Last inspection - End-item accept or reject
   a. The two major causes of bond failure (poor surface preparation and improper coating parameters)
   b. Visual inspection instruments and measuring tools
      (1) Workmanship samples
      (2) 10X magnifier
      (3) Micrometer or caliper
   c. Coating appearance
   d. Inspection checklist
   e. Acceptance standards

f. Defects, imperfections, and coating rejection criteria
g. Corrective action/avoiding malpractice

6. Review
7. Administer test

VI. INFERENCES. Additional material is available for further information about the various aspects of the thermal spray processes. A variety of literature is listed in the reference sections of the books used for this course.

VII. VISUAL AIDS.

A. Instructors may use the figures in this Manual to produce overhead transparencies as necessary for frustrating the various aspects of the thermal spray process. In some cases, local equipment can be expected to vary from the included figures enough to cause confusion. In these cases, the purposes of instruction may be better served by using locally available material to generate appropriate visual aids.

VIII. TRAINING AIDS (These may be prepared by the instructors or ordered from a facility with competent operators).

A. Surface preparation samples as follows:
1. Surface blasted with ball shot to provide clean surface but without angular profile.
2. Surface blasted for too short a time, leaving excessive contamination. (Near white metal calls for a maximum of 5% visible rust contamination, with no visible signs of oil, grease, dirt, and loose material or grease.)
3. Surface blasted too much, peening back and polishing as the profile is reduced. (NOTE: This is similar in appearance to blasting with broken-down grit.)
4. Surface contaminated with oil, grease, dirt, and loose material or dust.
5. Surface blasted correctly, giving a clean near-white or white metal surface with an angular profile appropriate to the coating type. The surface as prepared must be free of dust arising from other spraying operations, broken down blast media, etc.

B. Sample shafts with examples of various defects

C. Sample shafts with acceptable coatings

D. Practice forms for Quality Assurance record keeping

IX. TEST.

A. Thermal spray inspector written test. One set of test questions approved by NAVSEA follows on Page 5.

VISUAL INSPECTOR TEST

1. Name ten items that would cause a finished thermal sprayed coating to be rejected.
2. How should a finished coating be inspected?
3. Incorrect spraying parameters are one major cause of poorly bonded thermal sprayed coatings. What is the other major cause?
4. If something happens to a thermal sprayed coating during the process, it is permissible to spray over the visible coating defect. True False_
5. How can the anchor tooth depth of the grit blasted surface be measured?
6. (a) How many hours can be allowed between final surface preparation and thermal spraying of a machinery component?
   (b) If spraying does not start within 30 minutes from final blast what should be done?
7. What are the heat sources for the following thermal spray processes?
   (a) plasma powder
   (b) arc wire
   (c) flame powder
   (d) flame wire
8. When using a 1" to 2" micrometer, what would the diameter measurement be if the sleeve and thimble read as follows;

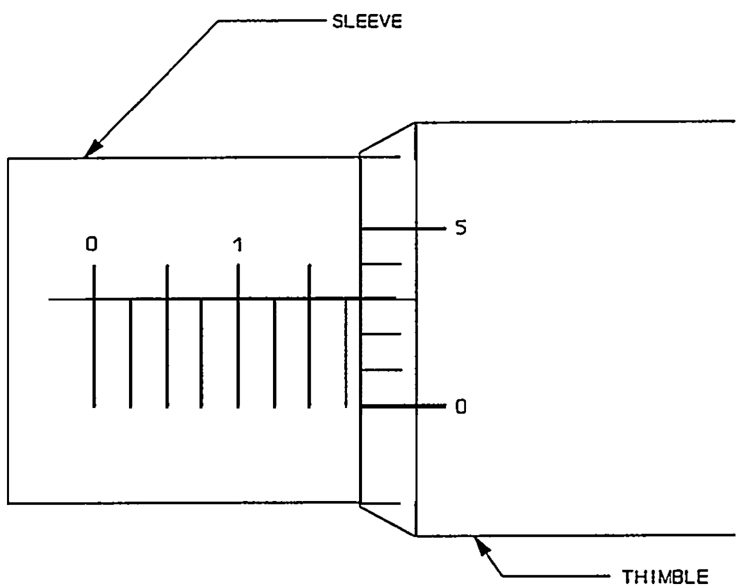


Figure 10.4 MICROMETER

9. Name the Military Standard used by the United States Navy as the acceptance standard for thermal sprayed machinery components.
10. What will happen to the coating if your fingers touch the prepared surface after final surface prerparation and before thermal spraying?

B. Answer key for written test

ANSWER KEY

1. Blisters, cracks, uneven coating thickness, excess porosity, chips or loosely adhering particles, evidence of oil or other contaminants, pit exposing the bond coat or substrate, coating separation, spatter or unmelted particles, incorrect coating thickness, poor surface finish, incorrect finished dimension.
2. Visually with 10x magnification and measured for dimensional requirements.
3. Poor surface preparation.
4. False.
5. Profile tape and micrometer.
6. (a) Two hours.
   (b) The prepared surface should be protected from oxidation and contamination and from handling and fingermarks.
7. (a) Plasma arc.
   (b) Electric arc.
   (c) Oxygen fuel flame.
   (d) Oxygen fuel flame.
8. 1.178”.
9. Mil-STD-1687 “Thermal Spray Processes for Naval Ship Machinery Applications”
10. The oil from your fingers that would be left on the surface of the component, may cause the coating to fail.

C. Practical examination - The practical examination consists of individual trainees inspecting a selection of the sample pieces listed in the training aids (VII, above) and determine the accept/reject condition of each sample. For each reject condition, the trainee must be able to cite the reason or cause of rejection.

Appendix 10.3
Plasma Powder Process Operator

I. **COURSE DESCRIPTION.** The following outline is a sample for a thermal spray training course for operators who have completed Basic and Inspector training. This is a 100 hour shop training course, designed to provide operators with the knowledge and experience necessary to setup, operate, and maintain plasma powder thermal spray equipment. Due to hazards and complexities involved, 20 hours of this course will be conducted in the classroom. The remainder will provide hands-on shop experience.

II. **OBJECTIVES.** Trainees who successfully complete this course will be able to demonstrate the following abilities:

A. Describe a plasma powder thermal spray system and explain in detail its principles of operation.
B. Setup and operate a plasma powder thermal spray system from a normal shutdown condition.
C. Perform normal maintenance and some of the basic trouble-shooting operations typical for a plasma powder thermal spray system.
D. Setup and use related equipment and tools as necessary to perform spray operator qualification test samples for one or more commonly used plasma powder thermal spray procedures.

III. PREREQUISITES. Prior to beginning this course, trainees must successfully complete the following courses:

A. Basic Thermal Spray Operator, Machinery Repair
B. Quality Assurance Inspector

IV. **HANDOUTS.** Trainees will be provided with the following material for reading and classroom work:

A. Operating manual for the specific system used in this training course.
B. Local process instruction or equivalent instruction used as the governing process document by the facility conducting this training course.
C. Checklists and setup sheets, as necessary
   1. These items should be the documents used by the facility where the trainees will be eventually working.
   2. If local documents are not available, the following items may be used or can serve as models for the writing of documents which suit local equipment and work practices.
      a. METCO 7M STARTUP PROCEDURE, Enclosure 1 of Section 7 in the Manual.

V. COURSE OUTLINE.

A. Introduction - read introductory statement for this appendix.
   1. Course Objectives - see Item II, above
   2. Definitions
      a. Thermal Spray
      b. Plasma Powder Process
      c. Others can be found as needed in the glossary of this manual.

B. Safety
   1. Review Safety Section of this Manual
   2. Equipment Manufacturer's Safety Measures.

c. Theory
   1. The thermal spray gun (repeat as necessary for each model spray gun used.)
      a. Construction
      b. Principles of operation
   2. Thermal spray materials (feedstock)
      a. Types available
      b. Types commonly used at this facility
      c. Typical applications
   3. Powder feeder
      a. Construction
      b. Principles of operation
   4. Power supply
   5. Related equipment
      a. Gas and gas regulators
      b. Cooling equipment
      c. Component turning equipment
   6. Controls
      a. Methods of control
      b. Parameters and settings
      c. Effects of parameter changes

D. Practice
   1. Hookups
      a. The installation
      b. Connection between components
      c. Setup for daily operations
         (1) Setting parameters
         (2) Handling spray material
         (3) Calculating speeds and feeds
   2. Spraying operations
      a. Practice component preparations
      b. Preheating and spraying
      c. Monitoring, measuring, and inspection
   3. Shutdown
      a. Spray material handling
      b. Disconnections

c. Cleaning of work space and components; equipment storage

4. Maintenance
    a. Items to be maintained by operators
    b. Items to be maintained by qualified maintenance personnel
    c. Maintenance supplies
    d. Troubleshooting and repairs

E. Testing

1. The written test for this section of training will be the completion of a Thermal Spray Job Control Record (TSJCR). Knowledge will also be evaluated by the instructor from feedback during training. Knowledge requirements are limited to the ability to properly setup and spray operator test specimens without prompting from the instructor.
2. Performance test. Trainees will set up equipment, as necessary, and spray the following sample coupons for at least one procedure as specified in Section 11.
    a. Five or more tensile test samples
    b. Two or more bend test samples
    c. Two or more microscopic evaluation samples

Appendix 10.4
Arc Wire Process Operator

I. **COURSE DESCRIPTION.** The following outline is a sample for a thermal spray training course for operators who have completed Basic and Inspector training. This is a 20 hour shop training course, designed to provide operators with the knowledge and experience necessary to setup, operate, and maintain arc wire thermal spray equipment.

II. **OBJECTIVES.** Trainees who successfully complete this course will be able to demonstrate the following abilities:

A. Describe an arc wire thermal spray system and explain in detail its principles of operation.
B. Setup and operate an arc wire thermal spray system from a normal shutdown condition.
C. Perform normal maintenance and some of the basic trouble-shooting operations typical for an arc wire thermal spray system.
D. Setup and use related equipment and tools as necessary to spray operator qualification test samples for one or more commonly used arc wire thermal spray procedures.

III. **PREREQUISITES.** Prior to beginning this course, trainees must successfully complete the following courses:

A. Basic Thermal Spray Operator, Machinery Repair
B. Quality Assurance Inspector

IV. **HANDOUTS.** Trainees will be provided with the following material for reading and classroom work:

A. Operating manual for the specific system used in this training course.
B. Local process instruction or equivalent instruction used as the governing process document by the facility conducting this training course.
C. Checklists and setup sheets, as necessary
   1. These items should be the documents used by the facility where the trainees will be eventually working.
   2. If local documents are not available, the following items may be used or can serve as models for writing documents which suit local equipment and work practices.
      a. Manufacturer's Startup Procedures
      b. The local facility's applicable SETUP DATA SHEETS

V. **COURSE OUTLINE.**

A. Introduction - read introductory statement for this appendix.
   1. Course Objectives - see Item II, above
   2. Definitions
      a. Thermal Spray
      b. Arc Wire Process
      c. Others can be found as needed in the glossary of this manual

B. Safety
   1. Review Safety Section of this Manual
   2. Equipment Manufacturer's Safety Measures
c. Theory
   1. The thermal spray gun (repeat as necessary for each model spray gun used.)
      a. Construction
      b. Principles of operation
   2. Thermal spray materials (feedstock)
      a. Types available
      b. Types commonly used at this facility
      c. Typical applications
   3. Wire feeder
      a. Construction
      b. Principles of operation
   4. Power supply
   5. Related equipment
      a. Gas and gas regulators
      b. Cooling equipment
      c. Component turning equipment
   6. Controls
      a. Methods of control
      b. Parameters and settings
      c. Effects of parameter changes
D. Practice
   1. Hookups
      a. The installation
      b. Connection between components
      c. Setup for daily operations
         (1) Setting parameters
         (2) Handling spray material
         (3) Calculating speeds and feeds
   2. Spraying operations
      a. Practice component preparations
      b. Preheating and spraying
      c. Monitoring, measuring, and inspection
   3. Shutdown
      a. Spray material handling
      b. Discomections
      c. Cleaning of work space and components; equipment storage
   4. Maintenance
      a. Items to be maintained by operators
      b. Items to be maintained by qualified maintenance personnel
      c. Maintenance supplies
      d. Troubleshooting and repairs

E. Testing

1. The written test for this section of training will be the completion of a Thermal Spiny Job Control Record (TSJCR). Knowledge will also be evaluated by the instructor from feedback during training. Knowledge requirements are limited to the ability to properly setup and spray operator test specimens without prompting from the instructor.
2. Performance test. Trainees will set up equipment, mask as necessary, and spray the following sample coupons for at least one procedure as specified in Section 11.
   a. Five or more tensile test samples
   b. Two or more bend test samples
   c. Two or more microscopic evaluation samples

Appendix 10.5
Flame Powder Process Operator

I. **COURSE DESCRIPTION.** The following outline is a sample for a thermal spray training course for operators who have completed Basic and Inspector training. This is a 40 hour shop training course, designed to provide operators with the knowledge and experience necessary to setup, operate, and maintain flame powder thermal spray equipment.

II. **OBJECTIVES.** Trainees who successfully complete this course will be able to demonstrate the following abilities:

A. Describe a flame powder thermal spray system and explain in detail its principles of operation.
B. Setup and operate a flame powder thermal spray system from a normal shutdown condition.
c. Perform normal maintenance and some of the basic trouble-shooting operations typical for a flame powder thermal spray system.
D. Setup and use related equipment and tools as necessary to spray operator qualification test samples for one or more commonly used flame powder thermal spray procedures.

III. **PREREQUISITES.** Prior to beginning this course, trainees must successfully complete the following courses:

A. Basic Thermal Spray Operator, Machinery Repair
B. Quality Assurance Inspector

IV. **HANDOUTS.** Trainees will be provided with the following material for reading and classroom work:

A. Operating manual for the specific system used in this training course.
B. Local process instruction or equivalent instruction used as the governing process document by the facility conducting this training course.
C. Checklists and setup sheets, as necessary
   1. These items should be the documents used by the facility where the trainees will be eventually working.
   2. If local documents are not available, the following items may be used or can serve as models for writing documents which suit local equipment and work practices.
      a. Manufacturer's Startup Procedures
      b. The local Facility's Applicable SETUP DATA SHEETS

V. **COURSE OUTLINE.**

A. Introduction - read introductory statement for this appendix.
   1. Course Objectives - see Item II, above
   2. Deffitions
      a. Thermal Spray
      b. Flame Powder Process
      c. Others can be found as needed in the glossary of this manual

B. Safety
   1. Review Safety Section of this Manual
   2. Equipment Manufacturer's Safety Measures
c. Theory
   1. The thermal spray gun (repeat as necessary for each model spray gun used.)
      a. Construction
      b. Principles of operation
   2. Thermal spray materials (feedstock)
      a. Types available
      b. Types commonly used at this facility
      c. Typical applications
   3. Powder feeder
      a. Construction
      b. Principles of operation
   4. Power supply
   5. Related equipment
      a. Gas and gas regulators
      b. Cooling equipment
      c. Component turning equipment
   6. Controls
      a. Methods of control
      b. Parameters and settings
      c. Effects of parameter changes
D. Practice
   1. Hookups
      a. The installation
      b. Connection between components
      c. Setup for daily operations
         (1) Setting parameters
         (2) Handling spray material
         (3) Calculating speeds and feeds
   2. Spraying operations
      a. Practice component preparations
      b. Preheating and spraying
      c. Monitoring, measuring, and inspection
   3. Shutdown
      a. Spray material handling
      b. Disconnections
      c. Cleaning and storing of work space and components
   4. Maintenance
      a. Items to be maintained by operators
      b. Items to be maintained by qualified maintenance personnel
      c. Maintenance supplies
      d. Troubleshooting and repairs

E. Testing

1. The written test for this section of training will be the completion of a Thermal Spray Job Control Record (TSJCR). Knowledge will also be evaluated by the instructor from feedback during training. Knowledge requirements are limited to the ability to properly setup and spray operator test specimens without prompting from the instructor.
2. Performance test. Trainees will set up equipment, mask as necessary, and spray the following sample coupons for at least one procedure as specified in Section 11.
   a. Five or more tensile test samples
   b. Two or more bend test samples
   c. Two or more microscopic evaluation samples

Appendix 10.6
F1ame Wire Process Operator

I. COURSE DESCRIPTION. The following outline is a sample for a thermal spray training course for operators who have completed Basic and Inspector training. This is a 40 hour shop training course, designed to provide operators with the knowledge and experience necessary to setup, operate, and maintain flame wire thermal spray equipment.

II. OBJECTIVES. Trainees who successfully complete this course will be able to demonstrate the following abilities:

A. Describe a flame wire thermal spray system and explain in detail its principles of operation.

B. Setup and operate a flame wire thermal spray system from a normal shutdown condition.

C. Perform normal maintenance and some of the basic trouble-shooting operations typical for a flame wire thermal spray system.

D. Setup and use related equipment and tools as necessary to spray operator qualification test samples for one or more commonly used flame wire thermal spray procedures.

III. PREREQUISITES. Prior to beginning this course, trainees must successfully complete the following courses:

A. Basic Thermal Spray Operator, Machinery Repair

B. Quality Assurance Inspector

IV. HANDOUTS. Trainees will be provided with the following material for reading and classroom work:

A. Operating manual for the specific system used in this training course.

B. Local process instruction or equivalent instruction used as the governing process document by the facility conducting this training course.

C. Checklists and setup sheets, as necessary

1. These items should be the documents used by the facility where the trainees will be eventually working.
2. If local documents are not available, the following items may be used or can serve as models for writing documents which suit local equipment and work practices.
    a. Manufacturer’s Startup Procedures
    b. The local Facility’s Applicable SETUT DATA SHEETS

V. COURSE OUTLINE.

A. Introduction - read introductory statement for this appendix.

1. Course Objectives - see Item II, above
2. Definitions
    a. Thermal Spray
    b. Flame Wire Process
    c. Others can be found as needed in the glossary of this manual

B. Safety
   1. Review Safety Section of this Manual
   2. Equipment Manufacturer's Safety Measures
c. Theory
   1. The thermal spray gun (repeat as necessary for each model spray gun used.)
      a. Construction
      b. Principles of operation
   2. Thermal spray materials (feedstock)
      a. Types available
      b. Types commonly used at this facility
      c. Typical applications
   3. Wire feeder
      a. Construction
      b. Principles of operation
   4. Power supply
   5. Related equipment
      a. Gas and gas regulators
      b. Cooling equipment
      c. Component turning equipment
   6. Controls
      a. Methods of control
      b. Parameters and settings
      c. Effects of parameter changes
D. Practice
   1. Hookups
      a. The installation
      b. Connection between components
      c. Setup for daily operations
         (1) Setting parameters
         (2) Handling spray material
         (3) Calculating speeds and feeds
   2. Spraying operations
      a. Practice component preparations
      b. Preheating and spraying
      c. Monitoring, measuring, and inspection
   3. Shutdown
      a. Spray material handling
      b. Disconnections
      c. Cleaning of work space and components; equipment storage
   4. Maintenance
      a. Items to be maintained by operators
      b. Items to be maintained by qualified maintenance personnel
      c. Maintenance supplies
      d. Troubleshooting and repairs

E. Testing

1. The written test for this section of training will be the completion of a Thermal Spray Job Control Record (TSJCR). Knowledge will also be evaluated by the instructor from feedback during training. Knowledge requirements are limited to the ability to properly setup and spray operator test specimens without prompting from the instructor.
2. Performance test. Trainees will set up equipment, mask as necessary, and spray the following sample coupons for at least one procedure as specified in Section 11.
   a. Five or more tensile test samples
   b. Two or more bend test samples
   c. Two or more microscopic evaluation samples

Appendix 10.7
High Velocity Oxygen Fuel Process Operator

I. COURSE DESCRIPTION. The foIlowing outline is a sample for a thermal spray training course for operators who have completed Basic and Inspector training. This is a 40 hour shop training course, designed to provide operators with the knowledge and experience necessary to setup, operate, and maintain high velocity oxygen fuel thermal spray equipment. Due to hazards and complexities involved, 20 hours of this course will be conducted in the classroom. The remainder will provide hands-on shop experience.

II. OBJECTIVES. Trainees who successfully complete this course will be able to demonstrate the following abilities:

A. Describe a high velocity oxygen fuel thermal spray system and explain in detail its principles of operation.

B. Setup and operate a high velocity oxygen fuel thermal spray system from a normal shutdown condition.

c. Perform normal maintenance and some of the basic trouble-shooting operations typical for a high velocity oxygen fuel thermal spray system.

D. Setup and use related equipment and tools as necessary to spray operator qualification test samples for one or more commonly used high velocity oxygen fuel thermal spiny procedures.

III. PREREQUISITES. Prior to beginniig this course, trainees must successfully complete the following courses:

A. Basic Thermal Spray Operator, Machinery Repair

B. Quality Assurance Inspector

IV. HANDOUTS. Trainees will be provided with the following material for reading and classroom work:

A. Operating manual for the specific system used in this training course.

B. Local process instruction or equivalent instruction used as the governing process document by the facility conducting this training course.

c. Checklists and setup sheets, as necessary

1. These items should be-the documents used by the facility where the trainees will be eventually working.
2. If local documents are not available, the following items can be used or can serve as models for writing documents which suit local equipment and work practices.
   a. Manufacturer’s Startup Procedures
   b. The local facility’s applicable SETUP DATA SHEETS

V. COURSE OUTLINE.

A. Introduction - read introductory statement for this appendix.

1. Course Objectives - see Item II, above
2. Definitions

a. Thermal Spray
b. High Velocity Oxygen Fuel Process
c. Others can be found as needed in the glossary of this manual

B. Safety
1. Review Safety Section of this Manual
2. Equipment Manufacturer's Safety Measures.

c . Theory
1. The thermal spray gun (repeat as necessary for each model gun used.)
a. Construction
b. Principles of operation
2. Thermal spray materials (feedstock)
a. Types available
b. Types commonly used at this facility
c. Typical applications
3. Powder feeder
a. Construction
b. Principles of operation
4. Power supply
5. Related equipment
a. Gas and gas regulators
b. Cooling equipment
c. Component turning equipment
6. Controls
a. Methods of control
b. Parameters and settings
c. Effects of parameter changes

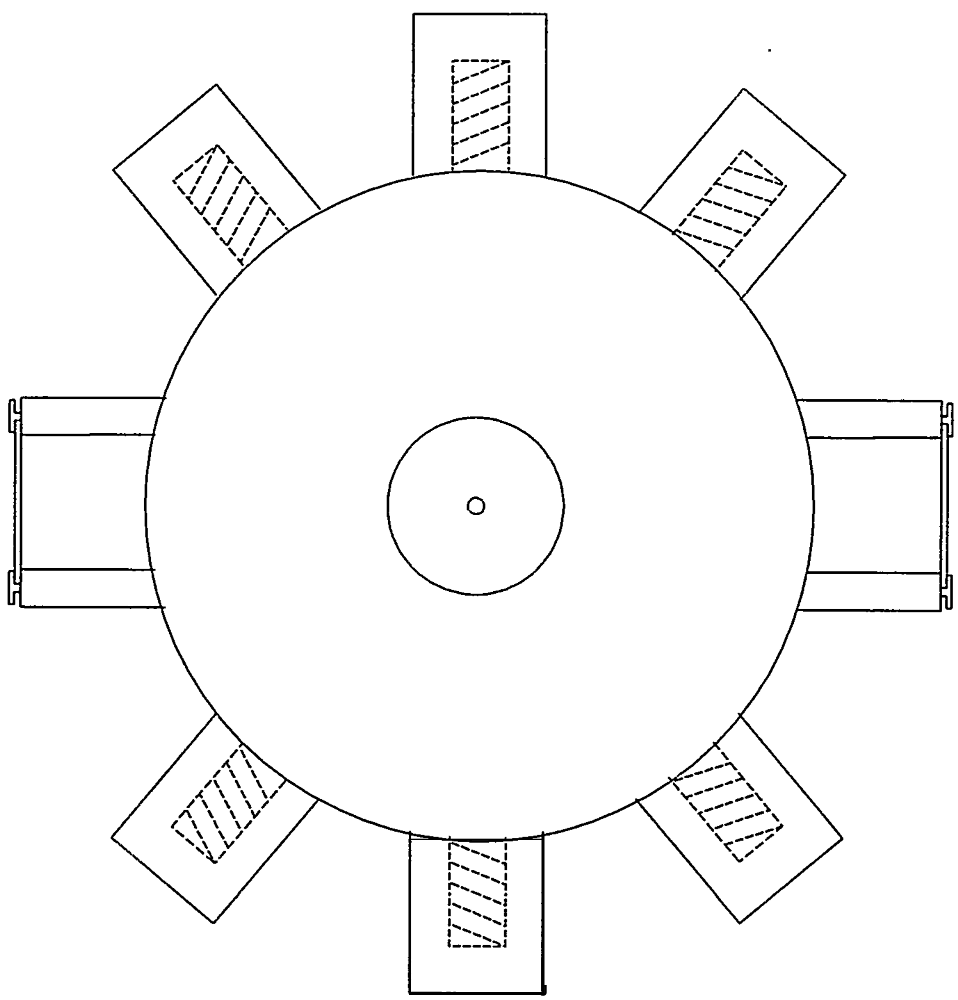
D. Practice
1. Hookups
a. The installation
b. Connection between components
c. Setup for daily operations
(1) Setting parameters
(2) Handling spray material
(3) Calculating speeds and feeds
2. Spraying operations
a. Practice component preparations
b. Preheating and spraying
c. Monitoring, measuring, and inspection
3. Shutdown
a. Spray material handling
b. Disconnections
c. Cleaning of work space and components

4. Maintenance
    a. Items to be maintained by operators
    b. Items to be maintained by qualified maintenance personnel
    c. Maintenance supplies
    d. Troubleshooting and repairs

E. Testing
1. The written test for this section of training will be the completion of a Thermal Spray Job Control Record (TSJCR). Knowledge will also be evaluated by the instructor from feedback during training. Knowledge requirements are limited to the ability to properly setup and spray operator test specimens without prompting from the instructor.
2. Performance test. Trainees will set up equipment, mask as necessary, and spray the following sample coupons for at least one procedure as specified in Section 11.
    a. Five or more tensile test samples
    b. Two or more bend test samples
    c. Two or more microscopic evaluation samples

SECTION 11

PROCEDURE/OPERATOR QUALIFICATIONS



PREPARED BY: PUGET SOUND NAVAL SHIPYARD

11 PROCEDURE/OPERATOR QUALIFICATIONS

INTRODUCTION

Before a ship building and/or ship repair facility can use the thermal spray process to repair shipboard machinery components for United States Naval Ships, they must have Naval Sea System Command (NAVSEA 03M) approved thermal spray procedures, qualified thermal spray operators, and meet all requirements of Military Standard 1687. This Section of the Manual provides thermal spray facilities with some of the procedures that have been approved by NAVSEA 03M and lists the requirements for obtaining new procedure/operator qualifications.

PROCEDURES

To obtain new NAVSEA approved thermal spray procedures, a shipbuilding/repair facility must complete the following tasks:

1. Thermal spray the required specimens.
2. Write parameters on how the specimens were sprayed.
3. Inspect and test the specimens.
4. Document thermal spray parameters and test results.
5. Write a request for procedure approval and send the request to Naval Sea Systems Command with the documented parameters and test results.

TEST SPECIMENS

Procedure qualification requires the thermal spraying of tensile bond specimens, bend test specimens, and specimens used for visual and microscopic examinations.

TENSILE BOND SPECIMENS

Tensile bond specimens used in thermal spray procedure qualifications must be machined to the shape and dimensions in Figure 11.1. At least five of these tensile bond specimens are required. (Some thermal spray facilities thermal spray six tensile bond specimens.) The tensile bond specimens are to be manufactured from the appropriate metal substrate material. (Substrate composition groups can be found on Page 11.6 of this Section.) The required coating thickness range for the tensile bond specimens is 0.016” to 0.020”. When qualifying a procedure for a two coat system, a bond coat thickness of 0.002” to 0.003” must be used.

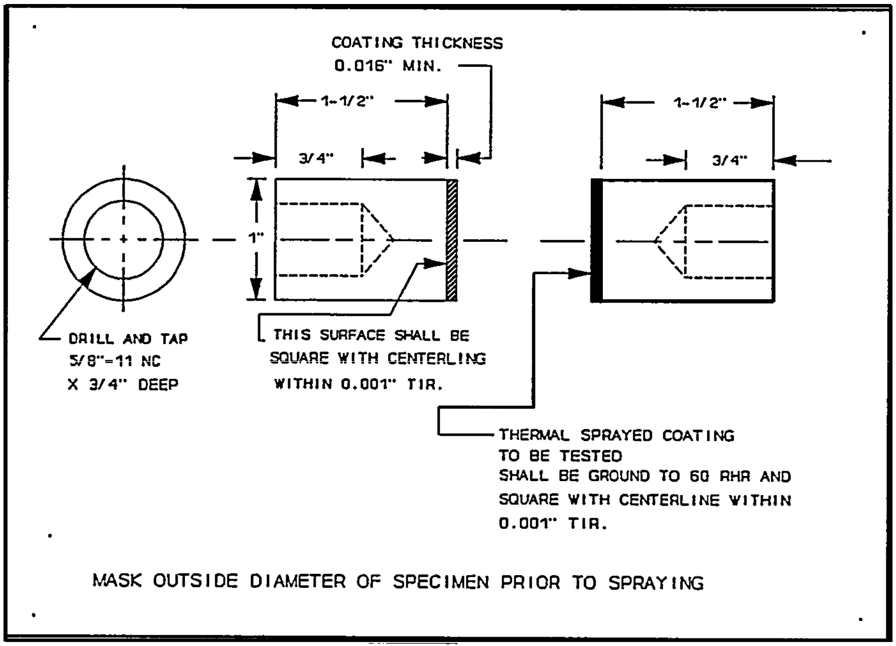


Figure 11.1 Tensile Bond Specimen

VISUAL EXAMINATION & BEND TEST SPECIMENS

For the visual examination and bend test the same specimens can be used. Visual examination and bend specimens are two panels approximately 3“ X 2“ X 0.050” (minimum) to ().()63” (maximum) manufactured from the appropriate substrate material (See Figure 11.2). The coating thickness to be applied for visual examination and bend test specimens is 0.008” ±0.002". If these specimens are to be used for a two coat system procedure, (bond coat and final coat) a bond coat thickness of 0.002” to 0.003” with a final coat a final coat thickness of at least 0.005” is applied.

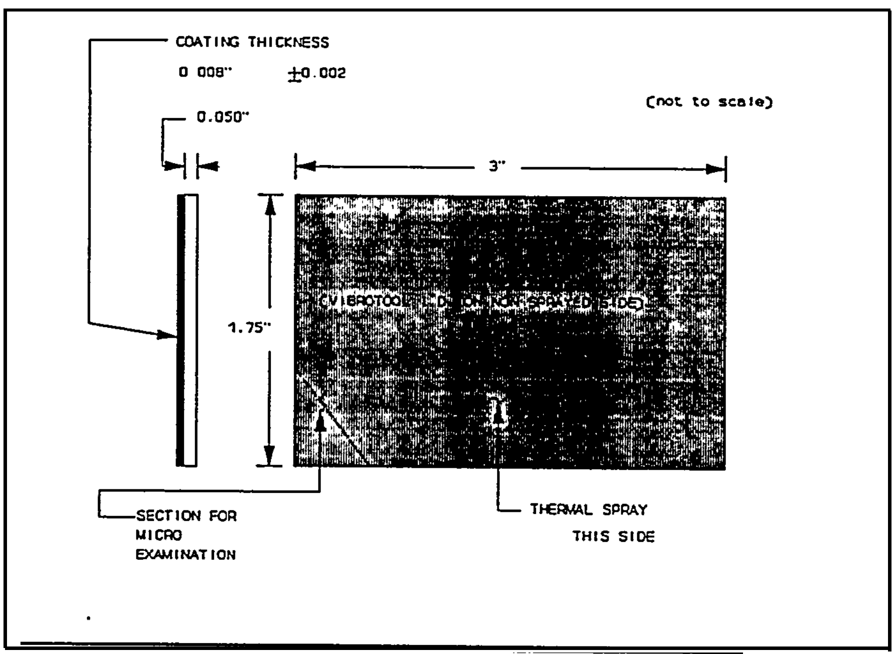


Figure 11.2 Visual Examination and Bend Test Specimens

MICROSCOPIC EXAMINATION SPECIMENS

The same type of panels used for the visual examination and bend test can be used for the microscopic examination specimens (See Figure 11.2). These require a coating thickness of a minimum of 0.008”. For some types of microscopic test equipment, the minimum thickness may be 0.020” or more. Each facility should consult with the laboratory conducting the destructive testing to determine the specific buildup requirements for this test. With a two coat system, a bond coat thickness of 0.002” to 0.003” with the remainder being the final coat. To meet the Military Standard 1687 requirements, all test specimens must be thermal sprayed using a rotating holding fixture. An example of a holding fixture that can be used is shown in Figure **11.3.**

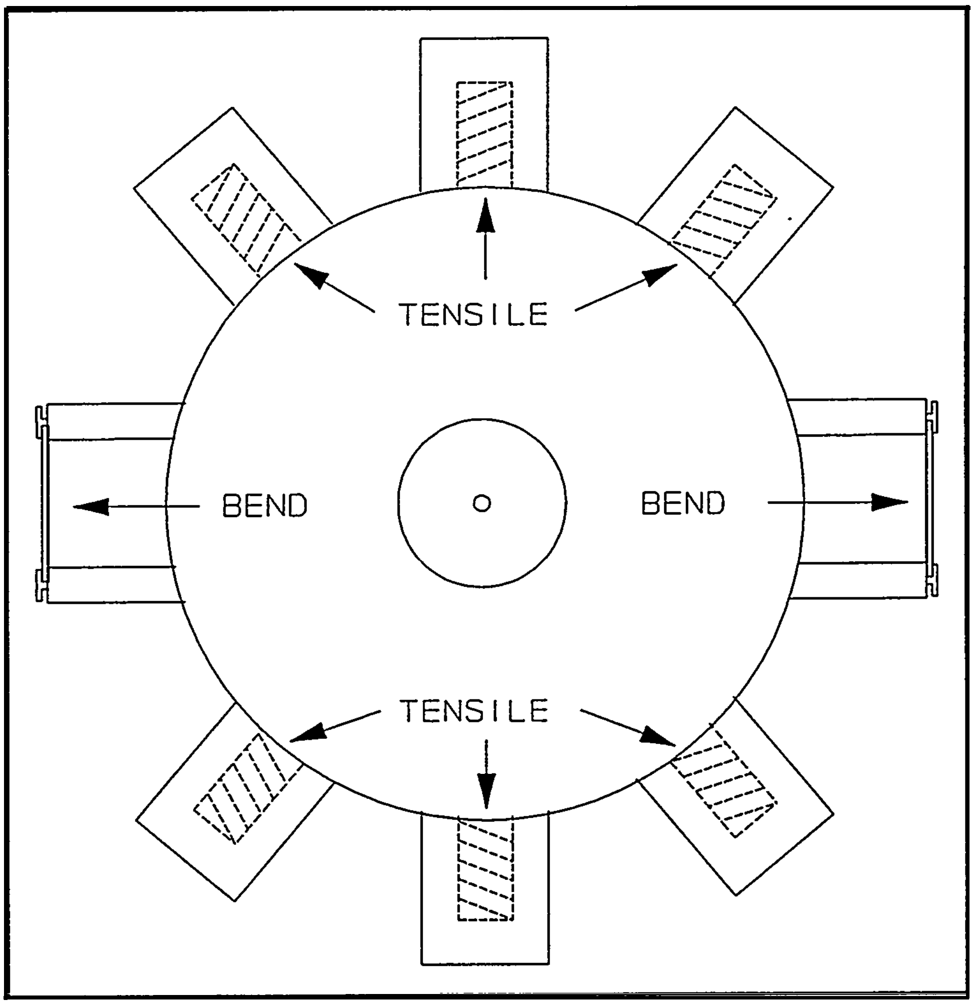


Figure **11.3 Rotating Holding Fixture**

EXAMINATION AND TESTING OF THE SPRAYED SPECIMENS

VISUAL EXAMINATION

The visual examination specimens must be inspected in the as-sprayed condition. Each of the samples are examined at 1OX-2OX magnification. The as-sprayed coating must have a uniform appearance. Surface defects of the coating must be limited to nodules not to exceed 0.045” in diameter and must not exceed 0.025” above the surrounding sprayed surface.

The coating must not contain any of the following;

1. Blisters
2. cracks
3. Chips or loose adhering particles
4. Pits exposing the bond coat or substrate
5. Coating separation

BEND TEST

The bend test specimens are bent approximately 180° on a l/2-inch diameter rod. The coating is on the tension surface of the bend. With the bend test, the coating is visually examined with the naked eye. Disbonding, delamination or gross cracking of the coating should not occur due to the bending. Small hairline cracks or alligator cracks of the coating near the bend are permissible. Ceramic coatings may exhibit flaking associated only with the edges of the bend sample.

MICROSCOPIC EXAMINATIONS

Sample cross section (0.75” to 1.00” long by 0.25” to 0.50” wide cut from the two thermal sprayed specimens are mounted in bakelite and metallographically prepared.

NOTE: Specimens which have been thermal sprayed with ceramic or other low-ductility material should be cut using a diamond abrasive wheel. Care should be taken to clamp the specimen in a way that there is no deflection or other stress in the coating. This will minimize fracturing in the coating. When grinding and polishing low ductility materials, the finishing steps are accomplished using diamond abrasive (6 X 3 micron) on low nap wheel cloths. Care in cutting, grinding and polishing will minimize particle pullout in the coating, which appears as porosity when viewed in microscopic cross section.

The cross-sectioned thermal sprayed surface shall be scanned at 100 to 200X for defects and uniformity. Oxides, porosity, and defects shall be measured at 200X magnification. The constituents of the coating shall be uniformly distributed and there shall be no separations between the coating and substrate. Anchor-tooth profile of the substrate shall be 0.002” to 0.004”. Bondline contamination (such as grit, disbonds and oxidation) shall be less than 10 percent. Unreacted globular particles shall be less than 10 percent of the coating cross-sectional area with the average diameter of the particles not exceeding 0.002”. See TABLE 11.1 in this Section for porosity and oxide content acceptability.

TENSILE BOND STRENGTH TESTING

The five tensile specimens are lightly grit blasted on the coated end, then cleaned. Like specimens, which have not been thermal spray coated, are bonded to the coated specimens. The following operations are performed to accomplish this effectively:

1. The uncoated blank is grit blasted to ensure a proper adhesive bond.

2. Heat curing "Scotch-Weld" structural adhesive is applied to both surfaces (assure that the surfaces to be bonded together are free of oil, grease, rust, paint or other foreign material which would inhibit adhesive bonding.
3. The two specimen pieces are assembled face-to-face in the alignment fixture of Figure 11.4. The entire fixture is inserted into an oven at 250°F for adhesive curing.

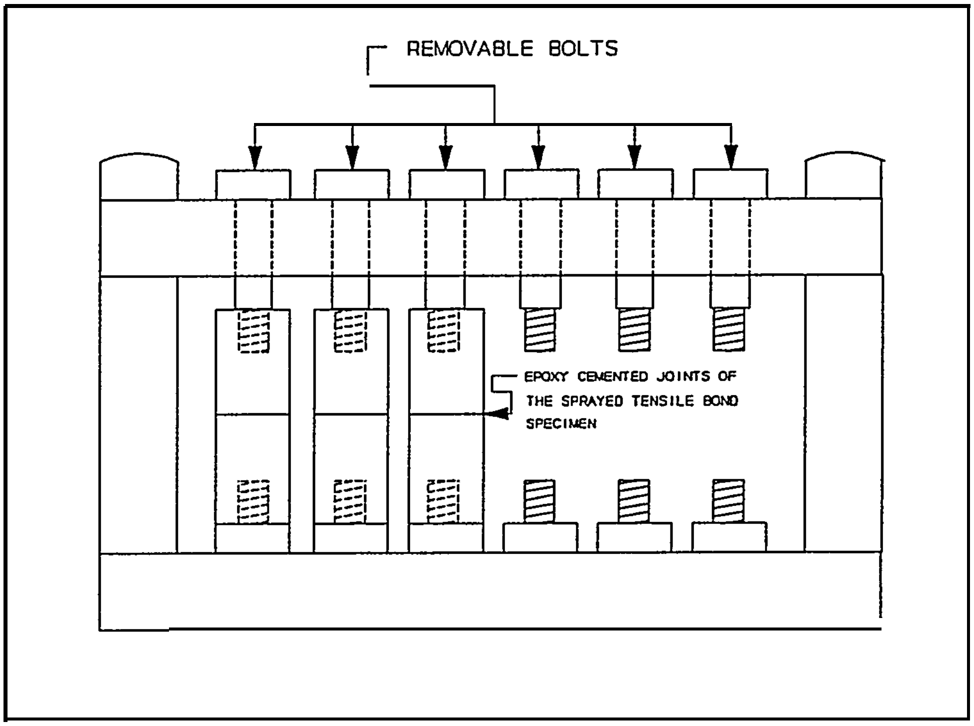


Figure 11.4 Tensile Bond Specimen Alignment Fixture

Each specimen assembly is subsequently pulled in tension until fracture occurs. The tensile strength is calculated using fracture load and the stress area of the specimen pieces. In addition to the average tensile strength and standard deviation of the five specimens, the region of failure is noted (Usually expressed as percent in regions, such as "within coating", "within adhesive", "at coating to substrate interface" - etc.). Tensile bond strengths are acceptable if they meet or exceed the values listed in TABLE 11.1 of this Section. Tensile bond strength less than the values listed in TABLE 11.1 are acceptable if approved by the Naval Sea System Command. If the procedure to be qualified is not listed in TABLE 11.1, acceptance will be determined by the Naval Sea Systems Command. If approved, NAVSEA will provide minimum acceptable bond strengths for subsequent operator qualification tests.

HARDNESS TESTING

Many thermal spray facilities perform hardness testing on coatings, even though Military Standard 1687 does not require it. This test is completed for information purposes only.

SUBSTRATE MATERIAL

A qualified procedure for a coating or coating system may be used on any substrate in the same composition group. There is no restriction or limitation on substrate hardness within a composition group. However, if the anchor-tooth profile measure on a production part is less than 0.002”, and this is due to high substrate hardness, then:

1. Qualification of a coating or coating system on a substrate of equal or greater hardness in the same composition group is required.
2. The anchor tooth profile measured on the qualification test samples must be no deeper than the profile obtained on the production part.

SUBSTRATE COMPOSITION GROUPS

1. Carbon, Stainless, and Low Alloy Steels
2. Nickel Base Alloys
3. Copper Base Alloys
4. Aluminum Base Alloys
5. Tin Base Alloys
6. Titanium Base Alloys

ESSENTIAL PROCEDURE ELEMENTS

A change in any of the essential elements listed below requires requalification of the procedure. However, minor changes in parameters are allowed.

a. Spray material type
b. Grit type and size
c. Gun type and model
d. Nozzle type and size
e. Primary gas type, pressure, and flow rate (for Plasma)
f. Secondary gas type and pressure (for plasma)
g. Powder port (for plasma arid flame powder)
h. Operating voltage (for plasma and arc wire)
i. Operating amperage
j. Surface speed
k. Traverse rate
l. Coating thickness per pass
m. Fuel gas type (for flame powder and flame wire)
n. Deposition rate (lbs per hour)

REQUESTING NAVSEA APPROVAL FOR PROCEDURE QUALIFICATION

When performing procedure qualification, all parameters for the thermal spray process used must be recorded on a Qualification Test Data Sheet. The parameters and values shall be recorded precisely as measured during spraying, such as 185 amps, 235° F preheat temperature, 0.001” soating thickness per pass.

See Enclosures (11.1) through (11.3) for examples of Qualification Test Data Sheets that can be used to list parameters when attempting to qualify a thermal spray procedure. Enclosure (11.4) is an example of how the test data can be documented. Enclosure (11.5) is an example of how a written request to NAVSEA can be developed by a thermal spray facility.

OPERATOR QUALIFICATION TEST REQUIREMENTS

The preparation, thermal spraying, and evaluation of visual and bend examination, microscopic examination, and tensile bond strength testing for operator qudlification are the same as for procedure qualification.

The visual and bend examination acceptance requirements for operator qualifications are the same as the acceptance requirements for procedure qualifications.

The general coating appearance at 200X magnification of the operator qualification shall meet the same acceptance criteria as the procedure qualification. Porosity and oxide content shall not exceed the limits in TABLE 11.1. For coatings not listed in TABLE 11.1, neither porosity content nor oxide content shall exceed the level established in procedure qualification tests by more than 5%.

The average bond strengths of the specimens for operator qualifications shall meet or exceed either the limits specified in TABLE 11.1, or the limits specified by NAVSEA for operator qualification.

ALTERNATE THERMAL SPRAY OPERATOR QUALIFICATION METHOD

An operator who qualifies a new procedure becomes qualifid to thermal spray that coating or coating system.

LIMITS OF CERTIFICATION

Personnel who meet the requirements for operator qualification tests become certified to perform spraying with the coating system and thermal spray process used in qualification testing.

MAINTENANCE OF CERTIFICATION

Certification of the operator shall be retained unless a period of six months has elapsed since the last production use of the thermal spray process.

TABLE 11.1 THERMAL SPRAY COATING PROPERTIES.

SPRAY MATERIAL	PROCESS[1]	SUBSTRATE[2]	MINIMUM AVERAGE BOND STRENGTH (lb/in^2)[3]	MINIMUM SINGLE SPECIMEN BOND STRENGTH (lb/in^2)[4]	MAXIMUM COATING THICKNESS (mils)[5]	MAXIMUM POROSITY (percent)[6]	MAXIMUM OXIDE (percent)[6]
Carbon steel							
- wire	AW	C	4500	3500	50	8	20
Austenitic stainless)(with bond coat)							
- wire	FW	C	4000	3000	50	6	20
420 Stainless							
- powder	PP	C	4500	3500	75	6	20
- wire	AW	C	4000	3000	50	8	20
- wire	FW	C	3500	2500	50	6	20
Aluminum-bronze							
- powder	FP, PP	B	4000	3000	125	6	20
- wire	FW	B	4500	3500	125	6	20
Nickel-aluminum							
- powder	FP, PP	C, N	4500	3500	50	6	20
Nickel-copper							
- powder	FP, PP	N	4500	3500	40	6	20
- wire	AW	N	4000	3000	40	8	20
Copper-nickel							
- powder	FP, PP	Cu	3000	2000	40	6	20
- wire	AW	Cu	3000	2000	40	8	20

SPRAY MATERIAL	PROCESS 1/	SUBSTRATE 2/	MINIMUM AVERAGE BOND STRENGTH (lb/in^2) 3/	MINIMUM SINGLE SPECIMEN BOND STRENGTH (lb/in^2) 4/	MAXIMUM COATING THICKNESS (mils) 5/	MAXIMUM POROSITY (percent) 6/	MAXIMUM OXIDE (percent) 6/
Alumina-titania - ceramic powder	FP, PP	C,N,B,Cu	7/3500	7/2500	15	4	NA
Babbitt - wire (with bond coat) - powder (with bond coat)	AW, FP	C	8/2250	8/1700	no limit	8	20

NOTES:

1/ Thermal spray processes are arc-wire (AW), flame-wire (FW), plasma-powder (PP), and flame-powder (FP) applied as single or dual coating systems. DuaI coating systems are identified by the bond coat systcm and finish coat system.

2/ Substrates arc C= carbon, low aIloy and stainless steel, cast iron, B = bronze, N = nickel base, Cu = copper base (other than bronze),

3/ The average specimen bond strengths of the five tested specimens shall meet or exceed the applicable bond strengths specified in TABLE 11.1. When limits for comparison are not specified in TABLE 11.1, the test data shall be submitted to NAVSEA for approval.

4/ The minimum single specimen bond strengths of the five tested specunens shall meet or exceed the applicable bond strengths specified in TABLE 11.1. When limits for comparison are not specified in TABLE 11.1, the test data shall be submitted to NAVSEA for approval.

5/ The maximum coating thickness that can be applied successfully depends on the specific component dimensions, the specific chemistry of the spray material and other factors.

6/ Requirements apply to both the top and finsh coats. Oxide requirement do not apply to ceramic powders.

7/ When applied over a bond coat.

8/ Specimens shall be machined and tested in accordance with ASTM C 633.

9/ For operator qualifications, the average and minimum single specimen bond strengths of the five tested specimens shall meet or exceed the applicable bond strengths specified in TABLE 11.1, or the minimum average and single specimen bond strengths approved for procedure qualification.

THERMAL SPRAY PROCEDURE DATA SHEETS

Enclosures (11.6) through (11.15) are Procedure Data Sheets that were developed from Naval Sea System Command (NAVSEA 03M) approved thermal spray procedures. These Procedure Data Sheets are used by United State Navy's thermal spray repair facilities and private ship building and repair facilities. To use the Procedures Data Sheets to thermal spray United States Naval Ship's machinery components, a ship repair facility must be certified by NAVSEA 03M to all requirements of Military Standard 1687 (MIL-STD-1687).

THERMAL SPRAY
CERTIFICATION TEST DATA
PLASMA POWDER

OPERATOR	
DATE SPRAYED:	
BASE MATERIAL:	
SURFACE PREPARATION:	
ANCHOR TOOTH HEIGHT:	
TEST FIXTURE TYPE	
BEND PLATE THICKNESS:	

ELEMENTS / PARAMETERS	BOND	**FINISH**
POWDER TYPE		
POWDER LOT #		
GUN TYPE		
NOZZLE TYPE		
POWDER PORT TYPE		
CROSS JETS (PSI)		
CROSS JETS (INCHES)		
POWER SUPPLY TYPE		
AMPS		
VOLTS		
POTENTIOMETER SETTING		
POWDER FEEDER TYPE		
METER WHEEL TYPE		
METER WHEEL RPM		
VIBRATOR (PSI)		
PRIMARY GAS TYPE		
SECONDARY GAS TYPE		
PRIMARY GAS PRESSURE (PSI)		
SECONDARY GAS PRESSURE (PSI)		
PRIMARY GAS FLOW (CFH)		
SECONDARY GAS FLOW (CFH)		
CARRIER GAS FLOW (CFH)		

ELEMENT/PARAMETERS	BOND		FINISH	
SPRAY DISTANCE				
PRE-HEAT °F				
MAX SPRAY TEMP °F				
SURFACE FT PER MIN				
TRAVEL SPEED				
THICKNESS PER PASS				
SPRAY RATE (LBS/HR)				
COATING THICKNESS				
2 BEND TEST				
1 MACRO				
6 TENSILE TEST				
1 HARDNESS TEST				
TEST RESULTS	PASS	FAIL	PASS	FAIL
BEND TEST				
MACRO TEST				
TENSILE TEST				
HARDNESS TEST				

FOR TEST RESULTS, SEE LAB REPORT #______________
TEST DATA VERIFIED BY ________________________
TEST DATA APPROVED BY ________________________

ESSENTIAL ELEMENTS NOT COVERED IN THIS PROCEDURE SHALL BE IN ACCORDANCE WITH PROCESS INSTRUCTION

THERMAL SPRAY
CERTIFICATION TEST DATA
ARCWIRE

OPERATOR	
DATE SPRAYED:	
BASE MATERIAL:	
SURFACE PREPARATION:	
ANCHOR TOOTH HEIGHT	
TEST FIXTURE TYPE:	
BEND PLATE THICKNESS:	

ELEMENTS/PARAMETERS	BOND	FINISH
WIRE TYPE		
WIRE SIZE		
WIRE LOT #		
GUN TYPE		
AIR NOZZLE TYPE		
POWER SUPPLY TYPE		
ATOMIZING AIR (PSI)		
AMPS		
VOLTAGE		
SPRAY DISTANCE		
SPRAY ANGLE		
PRE-HEAT °F		
THICKNESS PER PASS		
SURFACE FT PER MIN		
TRAVEL SPEED		
COATING THICKNESS		
2 BENDS TEST		
1 MACRO		
6 TENSILE TEST		
1 HARDNESS TEST		

ELEMENTS/PARAMETERS	BOND		FINISH	
TEST RESULTS	PASS	FAIL	PASS	FAIL
BEND TEST				
TENSILE TEST				
MACRO TESI’				
HARDNESS TEST				

FOR TEST RESULTS, SEE LAB REPORT #______________
TEST DATA VERIFIED BY __________________________
TEST DATA APPROVED BY __________________________
ESSENTIAL ELEMENTS NOT COVERED IN THIS PROCEDURE SHALL BE IN ACCORDANCE WITH PROCESS INSTRUCTION

THERMAL SPRAY
CERTIFICATION TEST DATA
FLAME POWDER PROCESS

OPERATOR		
DATE SPRAYED:		
BASE MATERIAL:		
SURFACE PREPARATION:		
ANCHOR TOOTH HEIGHT		
TEST FIXTURE TYPE		
BEND PLATE THICKNESS:		
ELEMENTS/PARAMETERS		
POWDER TYPE AND MANUFACTURER		
GUN TYPE		
NOZZLE MARKING		
AIR CAP TYPE		
ROTO JET TYPE		
COOLING AIR PRESSURE		
OXYGEN REGULATOR PSI		
FUEL REGULATOR PSI		
OXYGEN FLOWMETER		
FUEL FLOWMETER		
CARRIER GAS TYPE		
CARRIER GAS FLOWMETER SETTING		
CARRIER GAS REGULATOR PRESSURE		
POWDER FEEDER TYPE		
POWDER PORT SHAFT		
FEED RATE METER		
VIBRATOR AIR PRESSURE		
GUN TO WORK DISTANCE		
GUN ANGLE		
PREHEAT TEMPERATURE		

ELEMENTS/PARAMETERS	BOND		FINAL	
SPRAY RATE LBS/HR				
SURFACE FT PER MINUTE				
TRAVERSE RATE				
MAX SPRAY TEMP °F				
CROSS GET TYPE				
CROSS JET DISTANCE AND AIR PRESSURE				
COATING THICKNESS				
2 BEND TEST				
1 MACRO				
6 TENSILE TEST				
1 HARDNESS TEST				
TEST RESULTS	PASS	FAIL	PASS	FAIL
BEND TEST				
MACRO TEST				
TENSILE TEST				
HARDNESS TEST				

FOR TEST RESULTS, SEE LAB REPORT #______________
TEST DATA VERIFIED BY __________________________
TEST DATA APPROVED BY __________________________
ESSENTIAL ELEMENTS NOT COVERED IN THIS PROCEDURE SHALL BE IN ACCORDANCE WITH PROCESS INSTRUCTION

SUBJECT: THERMAL SPRAY REPORT

TO: WELDING ENGINEERING JOB ORDER: 9138-03300-000 REPORT NO: M-17838-91

1. PURPOSE OF TEST - PROCEDURE QUALIFICATION
   METCOLOY #2 ON CAST IRON

2. TENSILE TEST RESULTS

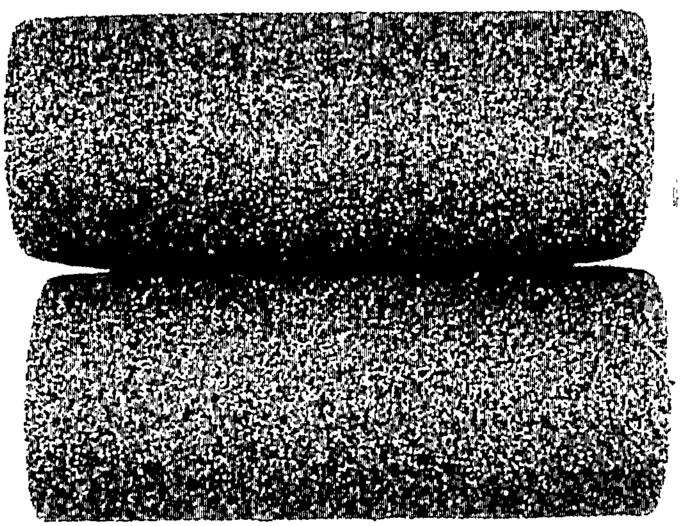
	BOND STRENGTH (PSI)	SAMPLE NO.
1.	9524	
2.	9740	
3.	9511	
4.	6392	
5.	9346	
6.	8620	

AVERAGE (PSI) 8856

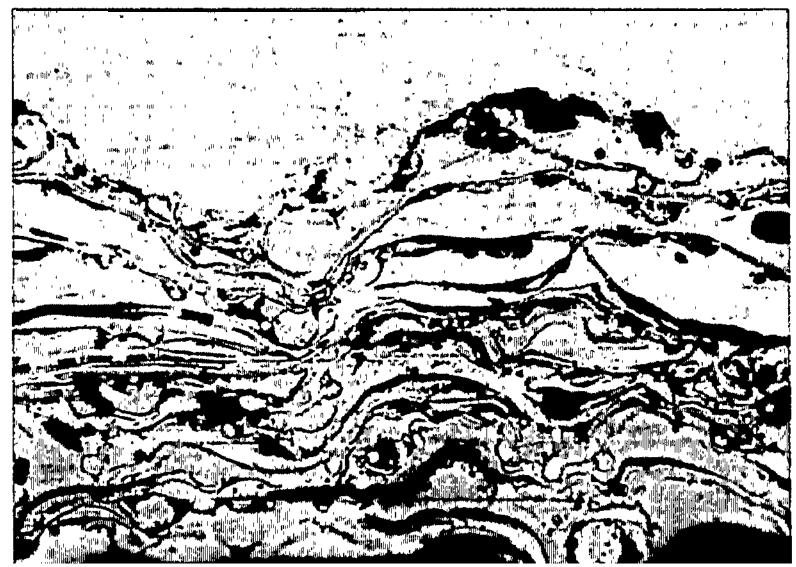
STANDARD DEVIATION (PSI) 1267

FAILURE REGION 5% METCOLOY #2/EPOXY

3. BEND SAMPLES
   BEND ANGLE 180 DEGREES BEND RADIUS



4. MICRO EXAMINATION
   MAGNIFICATION 100X
   OXIDE PERCENT 12% POROSITY PERCENT .4%



REVIEWER:

Enclosure (11.4)

Sheet 1 of 1

ACTION

9074
Ser 138/003-92

From: Commander, Puget Sound Naval Shipyard
To: Commander, Naval Sea Systems Command (SEA 03M)

Subj: THERMAL SPRAY PROCEDURE QUALFICATION

Refi (a) MIL-STD-1687 "Thermal Spray Processes for Naval Machinery Applications"

Encl: (1) Puget Sound Naval Shipyard Thermal Spray Procedure Specification No. 4329 Eutectic 21021/Metco 143 on 410 Stainless Steel
(2) Test Data for Enclosure (1)

1. Enclosures (1) and (2) are the procedure and supporting test data for qualifying Eutectic 21031 and Metco 143 thermal spray materials on 410 Stainless Steel using the Metco 7ME plasma spray system.

2. Reference (a) requires all thermal spray procedures be approved by NAVSEA (C/5142).

3. Puget Sound Naval Shipyard requests approval of the procedure specifications in enclosure (1) and the test data in enclosure (2). Approval is requested by 31 January 1992.

J. B. FISHLER
By direction

THERMAL SPRAY
PROCEDURE DATA SHEET
PLASMA POWDER
(METCO 7M EQUIPMENT)

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
POWDER	EUTECTIC 21031	METCO 143 (NOTE 1)
BASE MATERIAL (SUBSTRATE) TYPE(S)	IRON BASE ALLOYS	NA
SURFACE PREPARATION METHOD	ALUM. OXIDE 16-30	NA
ANCHOR TOOTH PROFILE	.002"-003"	NA
BLAST NOZZLE TO WORK DISTANCE	1-3 INCHES	NA
BLAST NOZZLE TO WORK ANGLE	90°	NA
GUN TYPE/MODEL	METCO 7 MB	METCO 7 MB
NOZZLE TYPE	GH	GE
INSULATOR:	METCO 7M 50	METCO 7M 50
POWDER PORT IDENTIFICATION	METCO #2	METCO #2
POWER SUPPLY TYPE	METCO 7 MR-230	METCO 7 MR-230
VOLTS	64-70	60-70
AMPS	500	600
PRIMARY GAS TYPE	ARGON	ARGON
SECONDARY GAS TYPE	HYDROGEN	HYDROGEN
PRIMARY GAS PRESSURE (PSI)	100	100
SECONDARY GAS PRESSURE (PSI)	50	50
PRIMARY GAS FLOW (CFH)	80	75
SECONDARY GAS FLOW (CFH)	10-20	10-20
POWDER FEEDER TYPE	METCO 3MP DUAL	METCO 3MP DUAL
POWDER CARRIER GAS TYPE	ARGON	ARGON
CARRIER GAS FLOW	37	37
METER WHEEL TYPE	METCO H	METCO H
METER WHEEL (RPM)	30 (NOTE 2)	15 (NOTE 2)
SPRAY RATE (LBS/HR)	12	5
GUN TO SUBSTRATE DISTANCE (INCHES)	4-6	3
GUN ANGLE	90°	90°
PRE-HEAT °F	200-225	200-225
MAX SURFACE TEMPERATURE °F	350	350
TYPICAL PART SURFACE SPEED (SFPM)	80-150	150-200
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	.200-.250	.200-.250
MIN. COATING THICKNESS/PASS	.001"	.0005"
MAX. COATING THICKNESS/PASS	.004"	.001"
MIN. COATING THICKNESS	.005"	005"
MAX. COATING THICKNESS (AS SPRAYED)	.050"	.025"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND

NOTE: 1. THE METCO 7M 80 COOLER ASSEMBLY SHALL BE USED DURING THE APPLICATION OF METCO 143 POWDER. AIR PRESSURE FOR THE COOLER ASSEMBLY SHALL BE 70 PSI, THE SETTING FOR THE CROSS JETS SHALL BE 3 INCHES.

2. USE AS A STARTING POINT. ADJUST AS NECESSARY TO OBTAIN SPRAY RATE SHOWN.

THERMAL SPRAY
PROCEDURE DATA SHEET
PLASMA POWDER
(METCO 7M EQUIPMENT

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
POWDER	EUTECTIC 21031	METCO 130 (NOTE) 1
BASE MATERIAL (SUBSTRATE) TYPE(S)	IRON BASED ALLOYS	NA
SURFACE PREPARATION METHOD	ALUM. OXIDE 16-30	NA
ANCHOR TOOTH PROFILE	.002"-003"	NA
BLAST NOZZLE TO WORK DISTANCE	2"-3"	NA
BLAST NOZZLE TO WORK ANGLE	90°	NA
GUN TYPE/MODEL	METCO 7 MB	METCO 7 MB
NOZZLE TYPE	GH	GH
INSULATOR	METCO 7M 50	METCO 7M 50
POWDER PORT IDENTIFICATION	METCO #2	METCO #2
POWER SUPPLY TYPE	METCO 7 MR-230	METCO 7 MR-230
VOLTS	64-70	70-80
AMPS	500	500
PRIMARY GAS TYPE	ARGON	ARGON
SECONDARY GAS TYPE	HYDROGEN	HYDROGEN
PRIMARY GAS PRESSURE (PSI)	100	100
SECONDARY GAS PRESSURE (PSI)	50	50
PRIMARY GAS FLOW (CFH)	80	80
SECONDARY GAS FLOW (CFH)	10-20	20-25
POWDER FEEDER TYPE	METCO 3MP DUAL	METCO 3MP DUAL
POWDER CARRIER GAS TYPE	ARGON	ARGON
CARRIER GAS FLOW	37	37
METER WHEEL TYPE	METCO H	METCO S
METER WHEEL (RPM)	30 (NOTE 2)	30 (NOTE 2)
SPRAY RATE (LBS/HR)	12	5
GUN TO SUBSTRATE DISTANCE (INCHES)	4-6	4-5
GUN ANGLE	90°	90°
PRE-HEAT °F	200-225	200-225
MAX SURFACE TEMPERATURE °F	350	350
TYPICAL PART SURFACE SPEED (SFPM)	80-150	150-200
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	.200-.250	.200-.250
MIN. COATING THICKNESS/PASS	.001"	.0003"
MAX. COATING THICKNESS/PASS	.006"	.0005"
MIN. COATING THICKNESS	.005"	.005"
MAX. COATING THICKNESS (AS SPRAYED)	.050"	.025"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND

NOIE 1. VIBRATOR AIR PRESSURE SHOULD BE SET AT 15 PSI WHEN APPLYING METCO 130 POWDER.
2. USE AS A STARTING POINT. ADJUST AS NECESSARY TO OBTAIN SPRAY RATE SHOWN.

THERMAL SPRAY
PROCEDURE DATA SHEET
PLASMA POWDER
(METCO 9M EQUIPMENT

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
POWDER	DRESSER PP-25	METCO 130
BASE MATERIAL (SUBSTRATE) TYPE(S)	NICKEL BASE ALLOYS	NA
SURFACE PREPARATION METHOD	ALUM. OXIDE 16-30	NA
ANCHOR TOOTH PROFILE	.002"-003"	NA
BLAST NOZZLE TO WORK DISTANCE	2"-3"	NA
BLAST NOZZLE TO WORK ANGLE	90°	NA
GUN TYPE/MODEL	METCO 9 MB	METCO 9 MB
NOZZLE TYPE	GH	GH
INSULATOR	METCO 7M 50	METCO 7M 50
POWDER PORT IDENTIFICATION	METCO #2	METCO #2
POWER SUPPLY TYPE	METCO 8 MR	METCO 8 MR
VOLTS	58-65	70-80
AMPS	500	500
PRIMARY GAS TYPE	ARGON	ARGON
SECONDARY GAS TYPE	HYDROGEN	HYDROGEN
PRIMARY GAS PRESSURE (PSI)	100	100
SECONDARY GAS PRESSURE (PSI)	50	50
PRIMARY GAS FLOW (CFH)	80	80
SECONDARY GAS FLOW (CFH)	5-15	20-25
POWDER FEEDER TYPE	METCO 6MP DUAL	METCO 6MP DUAL
POWDER CARRIER GAS TYPE	ARGON	ARGON
CARRIER GAS FLOW	37	37
METER WHEEL TYPE	METCO R2	METCO R1
METER WHEEL (RPM)	20 (NOTE 1)	40 (NOTE 1)
SPRAY RATE (LBS/HR)	7	5
GUN TO SUBSTRATE DISTANCE (INCHES)	5	4-5
GUN ANGLE	90°	90°
PRE-HEAT °F	200-225	200-225
MAX SURFACE TEMPERATURE °F	350	350
TYPICAL PART SURFACE SPEED (SFPM)	80-150	150-200
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	.200-.250	.200-.250
MIN. COATING THICKNESS/PASS	.001"	.0005"
MAX. COATING THICKNESS/PASS	.003"	.001"
MIN. COATING THICKNESS	.005"	.005"
MAX. COATING THICKNESS (AS SPRAYED)	.050"	.025"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND

NOTES: 1. USE AS A STARTING POINT. ADJUST AS NECESSARY TO OBTAIN SPRAY RATE SHOWN.

THERMAL SPRAY
PROCEDURE DATA SHEET
PLASMA POWDER
(METCO 7M EQUIPMENT)

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
POWDER	NA	EUTECTIC 21031
BASE MATERIAL (SUBSTRATE) TYPE(S)	NA	IRON BASE ALLOYS
SURFACE PREPARATION METHOD	NA	ALUM OXIDE 16-30
ANCHOR TOOTH PROFILE	NA	.002"-.003"
BLAST NOZZLE TO WORK DISTANCE	NA	2"-3"
BLAST NOZZLE TO WORK ANGLE	NA	90°
GUN TYPE/MODEL	NA	METCO 7 MB
NOZZLE TYPE	NA	GH
INSULATOR	NA	METCO 7M 50
POWDER PORT IDENTIFICATION	NA	METCO #2
POWER SUPPLY TYPE	NA	METCO 7 MR-230
VOLTS	NA	64-70
AMPS	NA	500
PRIMARY GAS TYPE	NA	ARGON
SECONDARY GAS TYPE	NA	HYDROGEN
PRIMARY GAS PRESSURE (PSI)	NA	100
SECONDARY GAS PRESSURE (PSI)	NA	50
PRIMARY GAS FLOW (CFH)	NA	80
SECONDARY GAS FLOW (CFH)	NA	10-20
POWDER FEEDER TYPE	NA	METCO 3MP DUAL
POWDER CARRIER GAS TYPE	NA	ARGON
CARRIER GAS FLOW	NA	37
METER WHEEL TYPE	NA	METCO H
METER WHEEL (RPM)	NA	30 (NOTE 1)
SPRAY RATE (LBS/HR)	NA	22-25
GUN TO SUBSTRATE DISTANCE (INCHES)	NA	4-6
GUN ANGLE	NA	90°
PRE-HEAT °F	NA	200-225
MAX SURFACE TEMPERATURE °F	NA	350
TYPICAL PART SURFACE SPEED (SFPM)	NA	80-150
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	NA	.200-.250
MIN. COATING THICKNESS/PASS	NA	.001"
MAX. COATING THICKNESS/PASS	NA	.004"
MIN. COATING THICKNESS	NA	.005"
MAX. COATING THICKNESS	NA	.050"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND OR TOOL

NOTES: 1. USE AS A STARTING POINT. ADJUST AS NECESSARY TO OBTAIN SPRAY RATE SHOWN.

THERMAL SPRAY
PROCEDURE DATA SHEET
PLASMA POWDER
METCO 7M EQUIPMENT)

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
POWDER	NA	EUTECTIC 21021
BASE MATERIAL (SUBSTRATE) TYPE(S)	NA	NICKEL BASE ALLOYS
SURFACE PREPARATION METHOD	NA	ALUM. OXIDE 16-30 MESH
ANCHOR TOOTH PROFILE	NA	.002"-.003"
BLAST NOZZLE TO WORK DISTANCE	NA	2"-3"
BLAST NOZZLE TO WORK ANGLE	NA	90°
GUN TYPE/MODEL	NA	METCO 7 MB
NOZZLE TYPE	NA	GH
INSULATOR	NA	METCO 7M 50
POWDER PORT IDENTIFICATION	NA	METCO #2
POWER SUPPLY TYPE	NA	METCO 7 MR-230
VOLTS	NA	65-75
AMPS	NA	500
PRIMARY GAS TYPE	NA	ARGON
SECONDARY GAS TYPE	NA	HYDROGEN
PRIMARY GAS PRESSURE (PSI)	NA	100
SECONDARY GAS PRESSURE (PSI)	NA	50
PRIMARY GAS FLOW (CFH)	NA	80
SECONDARY GAS FLOW (CFH)	NA	10-20
POWDER FEEDER TYPE	NA	METCO 3MP DUAL
POWDER CARRIER GAS TYPE	NA	ARGON
CARRIER GAS FLOW	NA	37
METER WHEEL TYPE	NA	METCO H
METER WHEEL (RPM)	NA	20 (NOTE 1)
SPRAY RATE (LBS/HR)	NA	25
GUN TO SUBSTRATE DISTANCE (INCHES)	NA	6
GUN ANGLE	NA	90°
PRE-HEAT °F	NA	200-225
MAX SURFACE TEMPERATURE °F	NA	350
TYPICAL PART SURFACE SPEED (SFPM)	NA	80-150
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	NA	.200-.250
MIN. COATING THICKNESS/PASS	NA	.001"
MAX. COATING THICKNESS/PASS	NA	.004"
MIN. COATING THICKNESS	NA	.005"
MAX. COATING THICKNESS	NA	.050"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND OR TOOL

NOTES: 1. USE AS A STARTING POINT. ADJUST AS NECESSARY TO OBTAIN SPRAY RATE SHOWN.

THERMAL SPRAY
PROCEDURE DATA SHEET
PLASMA POWDER
(METCO 9M EQUIPMENT

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
POWDER	NA	DRESSER PP-25
BASE MATERIAL (SUBSTRATE) TYPE(S)	NA	NICKEL BASE ALLOYS
SURFACE PREPARATION METHOD	NA	ALUM OXIDE 16-30
ANCHOR TOOTH PROFILE	NA	.002"-.003"
BLAST NOZZLE TO WORK DISTANCE	NA	2"-3"
BLAST NOZZLE TO WORK ANGLE	NA	90°
GUN TYPE/MODEL	NA	METCO 9 MB
NOZZLE TYPE	NA	GH
INSULATOR	NA	METCO 7M 50
POWDER PORT IDENTIFICATION	NA	METCO #2
POWER SUPPLY TYPE	NA	METCO 8 MR-230
VOLTS	NA	58-65
AMPS	NA	500
PRIMARY GAS TYPE	NA	ARGON
SECONDARY GAS TYPE	NA	HYDROGEN
PRIMARY GAS PRESSURE (PSI)	NA	100
SECONDARY GAS PRESSURE (PSI)	NA	50
PRIMARY GAS FLOW (CFH)	NA	80
SECONDARY GAS FLOW (CFH)	NA	5-15
POWDER FEEDER TYPE	NA	METCO 6MP DUAL
POWDER CARRIER GAS TYPE	NA	ARGON
CARRIER GAS FLOW	NA	37
METER WHEEL TYPE	NA	METCO R-2
METER WHEEL (RPM)	NA	20 (NOTE 1)
SPRAY RATE (LBS/HR)	NA	5-9
GUN TO SUBSTRATE DISTANCE (INCHES)	NA	5
GUN ANGLE	NA	90°
PRE-HEAT °F	NA	200-225
MAX SURFACE TEMPERATURE °F	NA	350
TYPICAL PART SURFACE SPEED (SFPM)	NA	80-150
TRAVERSE RATIO MIN/MAX (INCHES PER REVOLUTION)	NA	.200-.250
MIN. COATING THICKNESS/PASS	NA	.001"
MAX. COATING THICKNESS/PASS	NA	.003"
MIN. COATING THICKNESS	NA	.005"
MAX. COATING THICKNESS	NA	.050"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND OR TOOL

NOTES: 1. USE AS A STARTING POINT. ADJUST AS NECESSARY TO OBTAIN SPRAY RATE SHOWN.

THERMAL SPRAY
PROCEDURE DATA SHEET
PLASMA POWDER
(METCO 9M EQUIPMENT)

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
POWDER	NA	METCO 445
BASE MATERIAL (SUBSTRATE) TYPE(S)	NA	COPPER BASE ALLOYS
SURFACE PREPARATION METHOD	NA	ALUM OXIDE 16-30
ANCHOR TOOTH PROFILE	NA	.002"-.003"
BLAST NOZZLE TO WORK DISTANCE	NA	2"-3"
BLAST NOZZLE TO WORK ANGLE	NA	90°
GUN TYPE/MODEL	NA	METCO 9 MB
NOZZLE TYPE	NA	GH
INSULA		METCO 7M 50
OWDER PORT IDENTIFICATION		METCO #2
OWER SUPPLY TYPE	NA	METCO 8 MR-230
		64-70
AMPS	NA	500
PRIMARY GAS TYPE	NA	ARGON
ONDARY GAS TYP		HYDROGEN
PRIMARY PRESS (PS	N	100
SECONDARY GAS PRESSURE (PSI)	NA	50
PRIMARY GAS FLOW (CFH)	NA	
SECONDARY GAS FLOW (CFH)	NA	10-20
POWDER FEEDER TYPE	NA	METCO 6MP DUAL
POWDER CARRIER GAS TYPE	NA	ARGON
CARRIER GAS FLOW		37
ETER WHE TYP		METCO R-2
ETE WHEEL (RP		20 (NOTE 1)
SPRAY RATE	NA	15-20
GUN TO SUBSTRATE DISTANCE (INCHES)	NA	
GUN ANGLE	NA	90°
PRE-HEAT °F	NA	200-225
MAX SURFACE TEMPERATURE °F	NA	350
TYPICAL PART SURFACE SPEED (SFPM		80-150
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	NA	.200-.250
MIN. COATING THICKNESS/PASS	NA	.001"
MAX. COATING THICKNESS/PASS	NA	
MIN. COATING THICKNESS	NA	.005"
MAX. COATING THICKNESS	NA	
TYP		METCO AP
TYPE OF FINISHING	NA	GRIND OR TOOL

NOTES: 1. USE AS A STARTING POINT. ADJUST AS NECESSARY TO OBTAIN SPRAY RATE SHOWN.

THERMAL SPRAY
PROCEDURE DATA SHEET
- ARC WIRE PROCESS -
(THERMION 500 EQUIPMENT)

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
WIRE TYPE	NA	HASTELLOY C-22
WIRE DIAMETER	NA	1/16"
SUBSTRATE	NA	IRON BASE ALLOYS
GRIT TYPE AND SIZE	NA	ALUM OXIDE 16-30 MESH
ANCHOR TOOTH PROFILE	NA	.002"-.004"
BLAST NOZZLE TO WORK DISTANCE	NA	2"-3"
BLAST NOZZLE TO WORK ANGLE	NA	90°
GUN TYPE	NA	THERMION 500
POWER SUPPLY/ARC CONTROL UNIT	NA	PowCon 550
AMPERAGE	NA	195-205
VOLTAGE	NA	27-30
ATOMIZING AIR (PSI)	NA	95-105
GUN TO SUBSTRATE DISTANCE	NA	4" - 6"
GUN ANGLE	NA	90°
PRE-HEAT °F	NA	200-250
MAX SURFACE TEMPERATURE °F	NA	350
TYPICAL PART SURFACE SPEED (SFPM)	NA	80-150
TRAVERSE RATIO MIN/MAX (INCHES PER REVOLUTION)	NA	.200-.250
MIN. COATING THICKNESS/PASS	NA	.001"
MAX. COATING THICKNESS/PASS	NA	.004"
MIN. COATING THICKNESS	NA	.005"
MAX. COATING THICKNESS	NA	.100"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND

THERMAL SPRAY
PROCEDURE DATA SHEET
- ARC WIRE PROCESS -
(THERMION 500 EQUIPMENT)

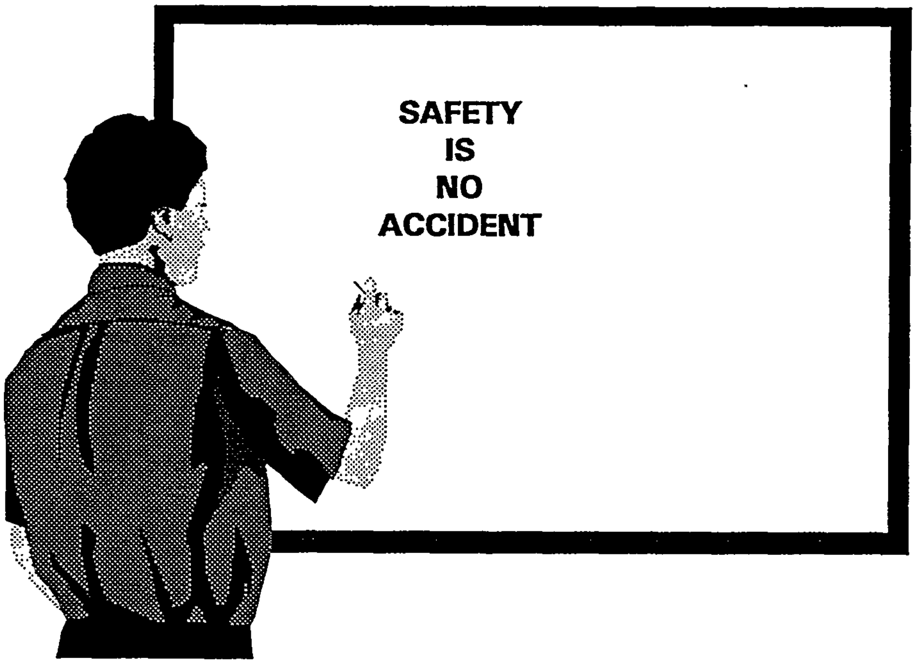
ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
WIRE TYPE	NA	TAFA 75-B
WIRE DIAMETER	NA	1/16"
SUBSTRATE	NA	IRON BASE ALLOYS
GRIT TYPE AND SIZE	NA	ALUM OXIDE 16-30
ANCHOR TOOTH PROFILE	NA	.002"-.003"
BLAST NOZZLE TO WORK DISTANCE	NA	2"-3"
BLAST NOZZLE TO WORK ANGLE	NA	90°
GUN TYPE	NA	THERMION 500
POWER SUPPLY/ARC CONTROL UNIT	NA	PowCon 550
AMPERAGE	NA	195-205
VOLTAGE	NA	25-30
ATOMIZING AIR (PSI)	NA	75-80
GUN TO SUBSTRATE DISTANCE	NA	4" - 6"
GUN ANGLE	NA	90°
PRE-HEAT °F	NA	200-250
MAX SURFACE TEMPERATURE °F	NA	350
TYPICAL PART SURFACE SPEED (SFPM)	NA	80-150
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	NA	.200-.250
MIN. COATING THICKNESS/PASS	NA	.001"
MAX. COATING THICKNESS/PASS	NA	.004"
MIN. COATING THICKNESS	NA	.005"
MAX. COATING THICKNESS	NA	.100"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND OR TOOL

THERMAL SPRAY
PROCEDURE DATA SHEET
- ARC WIRE PROCESS -
(THERMION 500 EQUIPMENT)

ELEMENTS/PARAMETERS	BOND COAT	FINISH COAT
WIRE TYPE	NA	AMPCO 10
WIRE DIAMETER	NA	1/16"
SUBSTRATE	NA	COPPER BASE ALLOYS
GRIT TYPE AND SIZE	NA	ALUM OXIDE 16-30
ANCHOR TOOTH PROFILE	NA	.002"-.004"
BLAST NOZZLE TO WORK DISTANCE	NA	2"-3"
BLAST NOZZLE TO WORK ANGLE	NA	90°
GUN TYPE	NA	THERMION 500
POWER SUPPLY/ARC CONTROL UNIT	NA	PowCon 550
AMPERAGE	NA	190-200
VOLTAGE	NA	25-35
ATOMIZING AIR (PSI)	NA	90-100
GUN TO SUBSTRATE DISTANCE	NA	4" - 6"
GUN ANGLE	NA	90°
PRE-HEAT °F	NA	200-250
MAX SURFACE TEMPERATURE °F	NA	350
TYPICAL PART SURFACE SPEED (SFPM)	NA	80-150
TRAVERSE RATIO MIN/MAX (INCHES/REVOLUTION)	NA	.200-.250
MIN. COATING THICKNESS/PASS	NA	.001"
MAX. COATING THICKNESS/PASS	NA	.004"
MIN. COATING THICKNESS	NA	.005"
MAX. COATING THICKNESS	NA	.100"
SEALER TYPE	NA	METCO AP
TYPE OF FINISHING	NA	GRIND OR TOOL

SECTION 12

SAFETY & ENVIRONMENT



PREPARED BY PUGET SOUND NAVAL SHIPYARD

INTRODUCTION TO SAFETY ISSUES

This section provides the Designer, Planner, and Mechanic with insights into the hazardous conditions which commonly exist in production and work environments. All too often, hazardous conditions are overlooked or not properly considered. This results in unecessary risk to personnel, equipment, and products. No one ever plans to have an accident. Accidents are, by definition, unplanned occurrences, too often resulting in injury, loss of life, or serious equipment damage.

The information provided and discussed in the following pages cannot address every potential hazard associated with thermal spraying or the subsequent safety precautions necessary to resolve each potential problem. This reference guide presents an overview of the types of hazards involved. This overview is to encourage everyone, from the Designer to the Mechanic, to look for potential hazards and to eliminate them before an accident occurs and becomes a costly lesson learned the hard way.

While safety is everyone's concern, the ultimate responsibility for a thermal spray operator's safety is the operator performing the work. Without a thorough understanding of the risks and the initiative to eliminate potential hazards in the interest of worker safety, injurious and costly accidents will occur. Thermal spray operators are responsible for using common sense and adhering to rules which apply to whatever happens to be the current situation.

In addition to common industrial hazards, the special hazards of the thermal spray process include the following:

- Solvents & Sealers
- Compressed & High Velocity Gases
- Dusts, Fumes, and High Velocity Particles
- High Temperatures
- High Intensity Light, Including Infrared & Ultraviolet
- High Intensity Noise

GENERAL SAFETY

The following general guidelines are to provide the operator a starting point for using common sense to keep the thermal spiny work place safe. These guidelines are not all inclusive. They do not cover all the areas of safety. However, they may provide sensitivity and a reminder for safety considerations to help prevent an accident.

GENERAL GUIDELINES

1. Always be alert and safety minded-this means NO HORSEPLAY!
2. Promptly correct or report any unsafe condition to supervision.
3. NEVER override, bypass, or remove any safety device, interlock, or notice.
4. Insure proper labeling, handling, and storage of all hazardous materials.

5. Always wear the following minimum PPE (personal protective equipment):
   (a) Clothing suitable for the job.
   (b) Safety glasses.
   (c) Safety shoes.
   (d) Eye and ear protection as required for the operation.
   (e) Special safety equipment as required for additional protection.
6. Maintain good housekeeping practices; insure that oil, water, or debris are not permitted to accumulate on floors or equipment.
7. Always use tools designed for the job and only if they are in good condition.
8. Take proper precautions to prevent injury from moving or rotating machinery.
9. Observe all precautions to prevent injuries from lifting or moving material and components.
10. Never operate load handling equipment unless properly trained and authorized, and then only by adhering to all safety limits.
11. Operate power tools according to manufacturer's and safety instructions.
12. Take precautions to avoid injury from compressed air.
13. Observe all precautions and procedures for handling high pressure compressed gas cylinders and inert gasses.
14. Take all possible measures to avoid injury from trip hazards and protruding objects, keeping in mind that the best preventions for these kinds of hazards are barriers or removal.
15. In case of any accident (even minor ones), report injuries immediately to supervision or to the industrial dispensary.

HAZARDS

Thermal spray operators work in a hazardous environment. In spite of the hazards, however, it is possible to work safely. By paying attention to detail and following common-sense guidelines, operators can minimize the risks of injury on the job. Operators consistently encounter the following five general categories of hazards:

1. Hazardous Materials
2. Compressed Gasses (Including Air, Fuel, & Oxygen)
3. Blasting Operations
4. Thermal Spiny Operations
5. Moving & Rotating Machinery

HAZARDOUS MATERIALS

The liquids commonly used for thermal spray operations contain powerful solvents. This is because surface contamination as slight as fingerprints contains enough oil to prevent a good bond. Thermal spray feedstock (spray material) may also present hazards to the operator for handling, storage, and spray operations. Therefore, operators must guard against toxic and flammability hazards when using any of these materials by observing the following guidelines:

1. Prevent fire or explosion by insuring that any containers within 50 feet of thermal spray operation are sealed and that thermal spray guns and compressed gas equipment are in proper operating condition.

2. Prevent absorption of toxic solvents through the skin by wearing protective clothing and non-permeable gloves during cleaning and sealing operations.
3. Prevent inhalation of toxic vapors by performing cleaning and sealing operations only with adequate ventilation. The best way to accomplish this is to use the spray booth ventilation (as long as spray operations are not conducted at the same time.)
4. Prevent formation of poisonous gasses by insuring that components are completely dry of solvent before preheating or spraying begin.
5. Prevent health problems from toxic materials by observing Material Safety Data Sheet (MSDS) instructions for ventilation, respiratory protection, protective eyewear, and handling of these materials.
6. Carefully follow safety instructions for each hazardous material.

COMPRESSED GASEOUS MATERIALS

Thermal spray processes use three categories of compressed gaseous which are compressed air, oxy-fuel gasses, and other compressed gasses, i.e., Argon, Hydrogen, Nitrogen, and Helium. Compressed air is typically used for blowing off components, grit blasting operations, and as anatomizing and/or cooling agent for spraying operations. Oxy-fuel gasses provide the heat for any of the flame processes, and one fuel (hydrogen) is utilized in many plasma operations. The others function as carrier and/or plasma gasses. Depending on the facility, the gasses may be piped to a manifold, liquified, or delivered in high pressure bottles. Observe the following precaution for handling these materials:

1. Never use any type of compressed gas for blowing down personnel or clothing. Oxygen or fuel can turn non-flammable clothing into an extreme fire hazard, and any kind of gas can enter the bloodstream to form embolisms resulting in hospitalization or death.
2. Follow manufacturers requirements and local procedures for storing, handling, and connecting these high pressure cylinders. If improperly handled, these cylinders are capable of becoming high-velocity projectiles capable of penetrating concrete walls.
3. Never operate compressed gas equipment without adequate ventilation. Consequences of failure to do this include the following:

    (a) Buildup of explosive gasses
    (b) Spontaneous combustion of some materials due to oxygen build up
    (c) Suffocation of personnel due to inert gas displacing oxygen

4. Frequently inspect all gas equipment and hoses for damage, leaks, loose connections and proper operation. In addition to providing an assurance of safety, this step also helps to provide consistently high quality spray coatings.

GRIT BLASTING SAFETY

When grit blasting is performed for surface preparation, another set of hazardous conditions occurs. High velocity air and grit through the blast nozzle produce loud noise. The blast stream can rapidly destroy unprotected human flesh and inject air and particles into human tissue. Finally, the blast impact produces dust which can clog breathing passages. Take the following minimum precautions to prevent injury from blasting operations:

1. Never aim the blast stream at any part of the human body, no matter how well it is protected.
2. Whenever possible, perform blasting remotely with automated equipment or within a small blast enclosure equipped with reach-through gloves.
3. If the blaster must use a large walk-in blast booth, specific training and certification must be carried out to assure the best possible protection against accidents. In addition to standard PPE, wear the following minimum protection:
   (a) Total body suit-up designed and approved for blasting.
   (b) Double eye protection.
   (c) Type CE air-supplied respirator.
   (d) Heavy duty leather or rubber gloves.
4. Wear safety glasses to protect eyes from any stray blast particles which might get through the primary protection.
5. Insure that adequate ventilation is provided to carry dust away from personnel.
6. Have the local safety office check sound levels to determine the proper level of hearing protection. Typically, single level protection, either ear plugs or ear muffs, is adequate.

THERMAL SPRAY OPERATION SAFETY

The main source of hazard during the thermal spraying operation is the intense heat produced by the spray gun. The heat combines with other factors to produce additional secondary hazards. These include dust and mist; radiated light, infrared and ultraviolet and high intensity noise. Each of these hazards produces its highest level of risk during hand-held operations. The dangers are reduced somewhat whenever the spray gun can be machine mounted. Remote operations help even more. For hand-held thermal spray operations, take the following precautions:

1. Radiated light, infrared, and ultraviolet can cause eye and skin damage. Wear flame resistant clothing to protect skin, and use falter lenses with hoods or face shields to protect the face and eyes. Lens shades should be as follows:

(a) Flame wire	Shades 2-4
(b) Flame powder	Shades 3-6
(c) Arc wire	Shades 9-12
(d) Plasma powder	Shades 9-12

NOTE For the arc wire process, shades 3-6 may be used when the gun is equipped with an arc shield.

WARNING

To protect personnel outside the spray facility from radiated light, covers should be placed over the windows during the spraying process.

2. Noise levels generated by the thermal spray process are sufficient to cause temporary deafness, permanent loss of hearing, and fatigue.

To prevent permanent hearing loss, ear muffs and/or properly fitted insert ear plugs must be worn by thermal spray operators and personnel in the immediate spray vicinity. This will reduce the high intensity noise levels to acceptable conditions. When spraying, the suitable ear protection is as follows:

(a) Flame wire	Insert ear plugs
(b) Flame powder	Insert ear plugs
(c) Arc wire	Insert ear plugs
(d) Plasma powder	Insert ear plugs and ear muffs

3. Thermal spraying generates dusts and fumes, causing a respiratory hazard. Adequate ventilation combined with the use of proper personal protective equipment will provide satisfactory protection. When thermal spraying in closed areas, a wet spray booth with an exhaust system should be used to minimize the hazardous concentration of dust and fumes. Appropriate personal respiratory protection should be worn during spraying and sealing operations. If operator discomfort such as dizziness or nausea develops, immediately stop spraying, and seek medical attention. With the evaluation of a health specialist and supervision, determine the cause for the discomfort and correct the cause before resuming the spraying operations.
4. Maintain thermal spray equipment in accordance with manufacturer's recommendations. Never light the flame wire gun without wire in the nozzle as flames may shoot back into the gun, causing equipment damage and operator injury. When lighting flame wire guns and flame powder guns, use a friction lighter; never use matches or a pocket lighter.
5. At least two people should be present at all times within the spray booth area during thermal spraying operations.
6. Flame-resistant clothing should be worn during thermal spraying operations to keep harmful flying particles from thermal sprayed material from skin contact. Aluminized clothing may be used, taking care radiation and ultraviolet light are not reflected onto unprotected skin areas.
7. Many thermal spray guns use an electric arc as a heat source. Observe manufacturer's directions in order to prevent electric shock hazards.

MACHINERY SAFETY

In addition to the other hazards associated with the process, powered machinery is frequently used to rotate components and manipulate thermal spray guns. At times, safety requirements involving this equipment may seem to conflict with spray requirements. If this occurs, call the local safety office or supervision for direction. Observe the following guidelines:

MACHINERY SAFETY GUIDELINES

1. Never leave the chuck key in a lathe.
2. Do not wear loose clothing or turned-up cuffs.
3. Never enter the work envelope of a powered-up robot or manipulation arm.
4. Perform regular maintenance on all equipment.
5. Cover gears, chucks, etc. whenever possible.
6. Always insure that mounting devices, such as chucks, tailstocks, fixtures and steady rests are properly mounted and adequate for the job.

7. Always insure that masking devices and other hardware are securely mounted on components which will be rotated in powered machinery for any thermal spray operation.

TRAINING FOR SAFETY

Operators, Supervisors, and Designers associated with mechanical trades need training in safe operations. This is especially true for the thermal spray process. Training provides the thermal spray operator information on the types of safety hazards which exist in the working environment. Even more important, it equips the operator to spot unsafe conditions under various circumstances, whether specific to thermal spraying or to some other related trade. As the safe working environment ethic becomes intrinsic to all workers, supervisors, planners, and design personnel, accidents and losses will be greatly reduced. Personnel involved with thermal spraying should become familiar with and follow American Welding Society's C2. 1 manual "RECOMMENDED SAFE PRACTICES FOR THERMAL SPRAYING", Chapter 074 of NAVSEA S9086-CH-STM-030, and Chapter 631 of NAVSEA S9086-VD-STM-000.

PLANNING FOR SAFETY

It is often the case during the planning and funding phase of a thermal spray project that safety is assumed to be a normal work practice and is just another unaccounted-for expense in the completion of the assignment. This can be a dangerous approach to doing business. This attitude or lack of awareness of what is required to ensure the safety of the thermal sprayers places an unnecessary burden on those production people trying to meet the schedules. Improperly identifying and subsequently under-funding safety requirements may cause production personnel, in their effort to complete a job in a timely, cost-effective manner, to overlook serious safety considerations. Safe working conditions for a thermal spray facility's personnel are not an incidental part or expense of doing business. Eye, ear, ventilation, respiration, skin, and fire protection add considerable cost to a job and must not be overlooked.

ENVIRONMENTAL CONTROLS

Environmental regulations vary widely from one location to another. Contact local safety and environmental offices to assure compliance with federal and state law, county and city ordinances, and agency regulations. Areas of special interest include the following:

PPE requirements
Ventilation requirements
Use of various types of hazardous material
Disposal of hazardous waste

Any material used or produced in the thermal spray process needs to be evaluated as potentially hazardous in the manufactured form and as waste after its intended use is complete. Hazardous materials and waste may include the following;

Sludge and dust produced in the spray operation.
Various types of powders and wires used as feedstock.
Hazardous (or potentially hazardous) liquids such as sealers, solvents, masking compounds, and waterfall booth waste water.

Facilities considering the addition of thermal spray to their overall capabilities must investigate and implement environmental controls prior to beginning spray operations. Environmental safety and controls are continuing to receive increased emphasis, and they are Law. Failure to comply with environmental regulations can and has resulted in criminal prosecution, for both employees and upper level management.

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